Impact Assessment of Large Scale Integration of Electric Vehicle Charging Infrastructure in the Electricity Distribution System

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ABBREVIATIONS

2W	Two Wheeler
3W	Three Wheeler
4W	Four Wheeler
AC	Alternating Current
ARAI	Automotive Research Association of India
BESCOM	Bangalore Electricity Supply Company
BESS	Battery Energy Storage System
BEV	Battery Electric Vehicles
BIS	Bureau of Indian Standards
BJT	Bipolar-Junction Transistor
BMS	Battery Management System
BMTC	Bangalore Metropolitan Transport Corporation
BYPL	BSES Yamuna Power Limited
CAGR	Compound annual growth rate
CC	Constant current
CCID	Charge Current Interruption Devices
CCS	Combined Charging System
CEA	Central Electricity Authority
CG	Connector Guns
COP	Conference of the Parties
CP	Charging Point
CPCB	Central Pollution Control Board
CPM	Charging Point Manager
CT	Current Transformer
CV	Constant Voltage
DC	Direct Current
DHI	Department of Heavy Industry
DISCOM	Distribution Company
DNO	Distribution Network Operator
DPC	Distribution Planning and Connection Code
DR	Demand Response
DSM	Demand Side Management
DSO	Distribution System Operator
DT	Distribution Transformer
EMC	Electro Magnetic Compatibility
EO	Energy Operator
ESQCR	Electricity Safety, Quality and Continuity Regulations
EVBC	EV Battery Chargers
EVM	EV Meter
EVMC	EV Manager Controller
EVs	Electric Vehicles
EVSA	EV electricity Supplier-Aggregator
EVSE	Electric Vehicle Supply Equipment
FAME	Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles
FCM	Final Customer Meter
GDP	Gross domestic product

GFCI	Ground Fault Current Interruption
GFI	Ground Fault Interrupts
GHG	Greenhouse gas
GIS	Geographic Information System
GOI	Government of India
GPS	Global Positioning System
GST	Goods and Services Tax
GTO	Gate Turn-Off thyristor
HT	High Tension
ICE	Internal combustion engine
ICT	Information and Communication Infrastructure and Technology
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IEGC	Indian Electricity Grid Code
IGBT	Insulated-Gate Bipolar Transistor
INDC	Intended Nationally Determined Contributions
IOT	Internet of Things
ISGF	India Smart Grid Forum
ISO	Independent System Operator
ITHD	Current Total Harmonic Distortion
KSRTC	Karnataka State Road Transport Corporation
LC	Low Capacity (As per existing EV battery trends in India)
LFP	Lithium Ferro Phosphate
LT	Low Tension
LV	Low Voltage
MNRE	Ministry of New and Renewable Energy
MoP	Ministry of Power
MOP	Ministry Of Power
MU	Million Units
MVR	Mayur Vihar
MW	Mega Watt
MWh	Mega Watt Hour
NEC	National Electrical Code
NEERI	National Environmental Engineering Research Institute
NEKRTC	North Eastern Karnataka Road Transport Corporation
NEMA	National Electrical Manufacturers Association
NITI	National Institution for Transforming India
NSP	Network Service Providers
NWKSRTC	North Western Karnataka Road Transport Corporation
OEM	Original Equipment Manufacturer
OLTC	On-Load Tap Changers
PC	Public Charger
PCC	Point of Common Coupling
PCS	Public Charging Stations
PF	Power Factor
PHEV	Plug-in Hybrid Electric Vehicles
PLC	Power Line Communication
PT	Power Transformer
PV	Photo Voltaic

PWM	Pulse Width Modulation
RCD	Residual Current Devices
SAE	Society of Automotive Engineers
SCADA	Supervisory control and data acquisition
SERC	State Electricity Regulatory Commission
SIAM	Society of Indian Automotive Manufacturers
SOC	State Of Charge
TCO	Total Cost of Ownership
TDD	Total Demand Distortion
THD	Total Harmonic Distortion
ToU	Time of Use
ToU	Time of Use
TS	Time Slot
TSO	Transmission System Operator
UPS	Uninterruptible Power Supply
VGF	Viability Gap Funding
VTHD	Voltage Total Harmonic Distortion
WPT	Wireless Power Transfer

01

About the Project

1.1 Introduction

Energy requirements of the power sector in India continue to rise due to urbanization, improvement in energy access, the growing transportation sector and industrialization. The COP 21, Paris Agreement (2016) are the comprehensive and far-reaching agreements by countries to reduce the implications of global warming. The severity of the threat of climate change and global warming has resulted in countries around the globe to undertake voluntary commitments of measures to reduce carbon footprint and greening of their development pathways. To combat with climate change, India has announced the integration of 175 GW power from renewable resources on the grid by 2022. With these drivers, there has been an exponential growth in the deployment of the renewables of all capacities, large and small in the past couple of years, which would continue well in the new era of industrial and economic development.

Global warming is one of the environmental reasons for leveraging the large-scale adoption of Electric Vehicles (EVs) as a means of mitigation. The transport sector accounts for about 23% of global energy-related Green-House Gas (GHG) emissions (IEA, 2015b). The ambitious GHG emissions reduction required to limit global warming to less than 2°C is unlikely to be achievable without a major contribution from the transport sector. World Health Organization in their study in December 2014 found that 13 of the 20 most polluted cities of the world are in India and Delhi tops this. It is not a noteworthy list. As per CPCB (Central Pollution Control Board) and NEERI (National Environmental Engineering Research Institute vehicles), the transport segment contributes to the highest level of air pollution in Delhi. [58]

It also should be noted that the replacement of ICE (Internal Combustion Engine) vehicles by EVs is not sufficient to effectively reduce GHG emissions, if the electricity used to charge EVs is generated through power plants using fossil fuels instead of renewable generation. It will only shift fossil fuel consumption from the transportation sector to the electricity sector, hardly reducing the global emissions of GHG.

Therefore, to significantly reduce the transportation sector GHG emissions, the policy makers have to ensure to increase the exploitation of renewables along with replacing the usage of conventional vehicles by EVs. These measures if implemented shall ensure a commendable decrease in the dependency on energy generated using fossil fuels to charge the EVs. Thereby, the energy consumed by the transportation sector will be fulfilled with “clean” electricity [1].

Indian economy is growing and hence the demand for vehicles is on constant rising. Data from Society of Indian Automotive Manufacturers (SIAM) records a total of more than 29 million units were produced between April 2017 and March 2018. This includes commercial vehicles, passenger cars, two-wheelers, three-wheelers and four-wheelers. The growth in production in the industry was 14.78% when compared to the same period in the previous year. India is expected to emerge as the third-largest market for automobiles by the year 2020. Automobile annual sales of different kinds of vehicles in India are presented in Table 1.1.

Table 1.1: Automobile sales trends (data from the Society of Indian automobile Manufacturers) [2]

Category	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18
Passenger Vehicles	26,65,015	25,03,509	26,01,236	27,89,208	30,47,582	32,87,965
Commercial Vehicles	7,93,211	6,32,851	6,14,948	6,85,704	7,14,082	8,56,453
Three Wheelers	5,38,290	4,80,085	5,32,626	5,38,208	5,11,879	6,35,698
Two Wheelers	1,37,97,185	1,48,06,778	1,59,75,561	1,64,55,851	1,75,89,738	2,01,92,672
Total	1,77,93,701	1,84,23,223	1,97,24,371	2,04,68,971	2,18,62,128	2,49,72,788

The Indian government has started an initiative with 30% electric vehicle sales by 2030 along with its clean energy generation. Continuing with its commitment towards promoting green transportation network, Government of India (GOI) has started different initiatives to promote electric vehicles. Intended Nationally Determined Contributions (INDC) and Faster Adoption and Manufacture of Electric Vehicles (FAME) are two such initiatives to increase EV penetration in the transportation system.

The integration of small quantities of EVs into the distribution grid will not impact the grid. However moderate to high penetration of EVs into distribution grid would most likely create some challenges in grid operation and management. Looking to EV as a simple uncontrollable load, it impacts the grid during peak load hours. Thus it is easy to foresee major congestion problems in already heavily loaded grids, low voltage problems in predominantly radial networks, peak load and energy losses increase and probably, large voltage drops and load imbalances between phases in LV grids. These problems may become a reality in the following years since the sales of passenger light-duty EVs will boost in upcoming years with initiatives from GoI.

There are two ways to accommodate the presence of EVs in the distribution grids while avoiding aforementioned problems. The first is to reinforce the existing power infrastructures and plan new networks in such a way that they can fully handle the EV integration, even for a large number of EVs. Yet, this rather expensive solution will require high investments in power infrastructures. The second is to develop and implement enhanced EV charging management strategies in the distribution networks along with Demand Side Management (DSM) functionalities that meets the grid and their owners' requirements. This approach provides the elasticity to these new loads and helps the management of power infrastructure to reduce/increase its values in such occurrence (for instance, branches' congestion levels or voltage problems). EV owners in turn, also benefit from these approaches given that the services they provide to the grid will be remunerated accordingly.

02

Electric Vehicle Charging Technologies

This section focuses on electrical charging technologies practiced worldwide. Figure 2.1 represents the factors affecting the evolution of charging technologies. It is important to understand that the charging location also decides the technology being adopted.

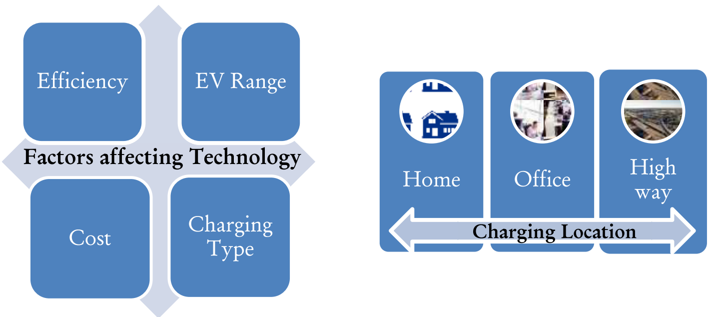


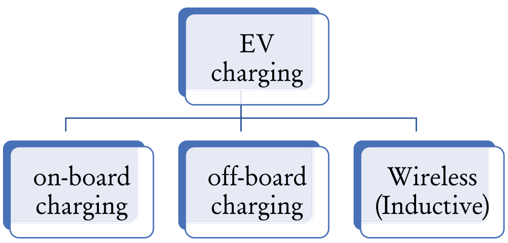
Figure 2.1: Factors that decides charging technologies

This section has been divided into four main categories that will be considered in the following sections:

1. Types of EV charging technologies
2. Types of EV charging systems and processes
3. Grid infrastructure required for EV charging stations
4. Software environment at charging station, DISCOM control centre and consumer

2.1 Types of EV Charging Technologies

The evolution in battery system technologies is crucial for the development of EVs from different aspects: efficiency, EV range, costs, etc. Charging/discharging techniques and capabilities also play an important role. They should be adopted for different situations (at home, at work, along highways, etc.) and meet drivers' needs in order to ensure EV usability and therefore improve their acceptability.



Types of Electric Vehicle Chargers

EV charging can be classified as on-board and off-board charging. These two methods have both unidirectional and bidirectional power flow capability, which means this design allows charging the EV battery from the grid as well as power injection back to the grid. Figure 2.2 shows the typical layout of on-board and off-board charging topology of an EV.

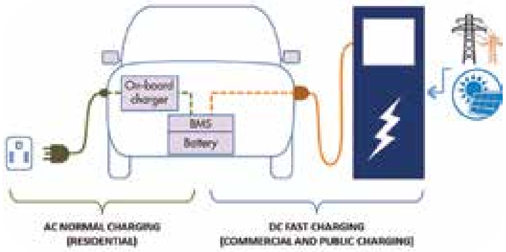


Figure 2.2: On-board and Off-board charging topology of EV [74]

In on-board charging, the charger assembly is placed in body of the vehicle and this restricts the size and weight because of the limited space that is available on the vehicle. These are mostly used in level-1 and level-2 AC chargers.

In off-board charging, the charger assembly is shifted off board and the rectified output of the AC-DC converter will be given directly to the EV charging inlet. This is mostly used on fast charging.

Most of the first generation EVs have the capability for AC charging and this is widely seen as the dominant form of vehicle charging. Present generation EVs are built with the capability to be charged at both AC and DC charging stations (DC charging is used for higher rate, faster charging applications). For instance, Nissan and Mitsubishi EV models have such feature and provide connectors for both Level 1 and Level 2 charging connectors while purchasing the vehicle. Level 1 and Level 2 EV charging are the most common and are found in most domestic charging station installations, while DC 'fast' charging is most often associated with operations in commercial charging station or fleet charging environments.

2.1.1 Level 1 AC Charging

Level 1 AC charging uses a standard 120-volt, single-phase, three-prong grounded electrical outlet (NEMA 5-15R standard plug) to charge an EV with around 15-20A of current [3]. Level 1 charging outlets should have ground fault interrupts (GFI) installed and 15A minimum branch circuit protection. Charging times for all EVs vary widely depending on the size of the on-board energy storage system and the driving habits of the operator. Level 1 charging is most effective when the vehicle can be recharged in less than 8 to 10 hours (about 30-40 miles of electric driving). For example, using Level 1 to fully recharge a Chevrolet Volt will take about 8-10 hours while fully recharging a Nissan Leaf takes up to 20-24 hours [4]. The Level 1 EVSE (EV Supply Equipment) is typically provided with the new vehicle, so Level 1 charging has zero additional cost to the EV owner as long as an outlet is available near the vehicle parking location.

In India, AC001 is the equivalent charger for Level-1 AC charger [48]. AC001 refers charging point at 230V standard single phase AC supply with a maximum output of 15A and at a maximum output power of 3.3kW. EVs with on-board charger will be connected to AC001 charger.

2.1.2 Level 2 AC Charging

Level-2 charging is used for both public and private applications. Level 2 EVSEs require 208-240-volt single phase supply with up to 80A maximum continuous current [3]. EVs with 60-80 miles range requires around 3-7 hours for full charging. Level 2 charging service also requires additional grounding, personal protection system features, a no-load make/break interlock connection, and a safety breakaway for the cable & connector. In India, Type 2 AC charger with minimum 22 kW is adopted at public charging stations [35]. However, as India is unlikely to have on-board chargers with higher rating in near future, the definition and building of AC fast charger beyond 3.3 kW will be adopted accordingly by Standards committee [48].

2.1.3 DC Fast Charging

Fast charging is used for rapid recharges of EV batteries and will most likely be found in commercial stations and EV corporate fleet depots. Many manufacturers will include a fast-charge connection in addition to Level 1 or Level 2 charging connections on most EVs, giving owners the option of quickly recharging their vehicles.

In India, DC fast charging is classified into two categories based on power and voltage ratings: Level 1 DC charger and Level 2 DC charger [48].

Level 1 DC chargers: Public off-board DC Chargers at output voltage of 48V / 72V, with power outputs of 10 kW/15 kW with maximum current of up to 200A.

Level 2 DC chargers: Public off-board DC Chargers at output voltage up to 1000V, with power outputs of 30 kW/150 kW.

Summary of AC and DC charging technologies are presented in Table 2.1.

Table 2.1: Characteristics of charging levels as defined by the SAE and charging modes as defined by the IEC [7]

Charging level	Voltage	Charging mode	Protection type	Typical power	Location
Level 1	120 V AC	-	None or Breaker in cable	1.2-1.8 kW AC	Primarily residential in North America
Level 2	200-240 V AC	Mode 1	None	3.6-11 kW AC	Wall socket in Europe; Primarily for 2 & 3 Wheelers
		Mode 2	Pilot function and breaker in cable	3.6-22 kW AC	Home and workplace with cable or basic station
		Mode 3	Pilot function and breaker in hardwired charging station	3.6-22 kW AC	Home, workplace and public with hardwired station
Fast Charging	400-1000 V DC	Mode 4	Monitoring and communication between vehicle and EVSE	50 kW or more	Public, frequently intercity
Notes: V=Volts; AC= alternating current; DC= direct current; kW=kilowatt					

2.1.4 Wireless Charging

Wireless charging is a breakthrough technology that allows an EV owner to charge the vehicle using either inductive or capacitive power transfer techniques while in motion. The power generated by wind or solar resources nearby are connected to the road systems that are delivered wirelessly. Such vehicles can have smaller batteries that results in cost reduction of the vehicle and accelerate its adoption.

The technology to enable effective dynamic Wireless Power Transfer (WPT) is still in nascent stage. It is of two types [5] as the following:

1. Inductive Wireless Power Transfer

Inductive WPT uses coils which are enabled in roadway and in EV, are coupled through magnetic fields to charge the battery in EV. However, for magnetic flux guidance and shielding requires ferrite cores, making them expensive and bulky. Also, to limit the losses in the ferrites, the operating frequency is limited to 100 kHz which results in larger size of coils and low power transfer densities. The disadvantage of this technique is that, very high-power capability coils are needed to deliver the required energy to the vehicle in very less time frames during which the vehicle passes over a charging coil. Because of the above-mentioned reasons, inductive WPT is yet to become commercially viable. Schematic model of Inductive WPT is shown in Figure 2.3.

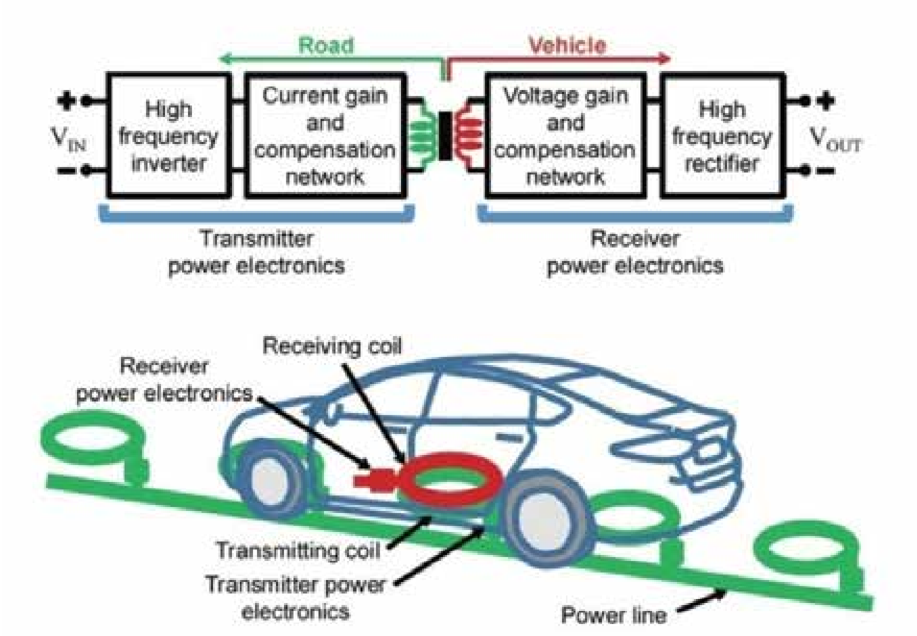


Figure 2.3: Inductive wireless power transfer schematic model [5]

2. Capacitive Wireless Power Transfer

Capacitive WPT uses coils which are enabled in roadway and in EVs which are coupled through electric fields to charge the battery in EVs. These are potentially advantageous than inductive charging because of the relatively directed nature of electric field which minimizes the requirement of electromagnetic field shielding. This type of charging does not use ferrites and because of this feature, the charging systems can operate with high frequencies that enable them to be compact and less expensive. But, because of the small amount of capacitance between the road and the EV plates, the power transfer will be effective only at higher frequencies making the design highly challenging. Schematic model of captive WPT is shown in Figure 2.4.

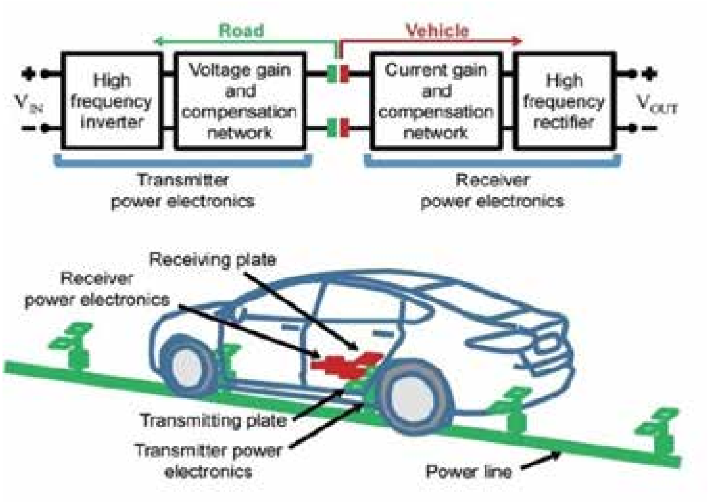


Figure 2.4: Capacitive wireless power transfer schematic model [5]

The major challenges associated with capacitive charging for EV are the following:

- To achieve high power transfer density at high efficiencies while meeting electromagnetic safety requirements
- To maintain effective power transfer depending on couplers' relative position changes

Conclusions on Charging Technologies:

Presently draft standards for AC001, DC001 and DC002 are available for EV chargers [48]. However, the clear standard for Level-2 AC charger does not exist for residential place. Level 2 AC chargers say AC002 can be standardized as per the International standards for both at residential place and at charging station. Proposed standards for charging technologies for India taking inputs from [48] are presented in Table 2.2.

Table 2.2: Proposed charging capacities for India

Charging level	Voltage	Charging mode	Typical power	Location
Level 1 AC, AC001	230 V AC, 1-phase	-	3.3kW, AC	Residential and workplace
Level 2 AC, AC002	415 V AC, 3-phase	Mode 1	Up to 10 kW AC	Residential and workplace
		Mode 2	Up to 44 kW AC	Workplace, public and private charging station
Level 1 DC, DC001	48/72 V	-	10/15 kW	Workplace, private and public charging station
Level 2 DC, DC 002	Up to 1000 V DC	-	Up to 250 kW	Public, private charging station, intercity

2.2 Electric Vehicle Supply Equipment (EVSE)

Electric Vehicle Supply Equipment (EVSE) is a component in EV infrastructure that supplies electrical energy from an electricity source to recharge the EV batteries.

What is EVSE?

The National Electric Code (NEC) defines EVSE as: "The conductors, including the ungrounded, grounded, and equipment grounding conductors and the electric vehicle connectors, attachment plugs, and all other fittings, devices, power outlets, or apparatus installed specifically for the purpose of delivering energy from the premises wiring to the electric vehicle". [56]

Figure 2.5: EVSE installed at BESCOM [44]

For wet and/or outdoor locations, the current NEC requires the use of Ground Fault Current Interruption (GFCI) devices. The GFCI is a protection device that operates on the principle of monitoring the imbalance of current between the circuits, ungrounded and grounded conductor. It de-energises a circuit or a portion of it within an established period of time when current to ground exceeds a predetermined value that is less than that required to operate the overcurrent protective device of the supply circuit. The NEC requires GFCI outlets to be installed near sinks, garages and in outdoor locations. Since there is no way to ensure that an EV is plugged into a GFCI protected outlet in every instance, the NEC mandates that the vehicle charge cord carries an integral ground fault protection device. To distinguish these devices from typical GFCIs, they are referred to as Charge Current Interruption Devices (CCID) [4]. To support the above statement, the provisions mentioned by NEC in Article 625 [56] states that, an electric vehicle should be connected to a supply of electricity by conductive-cable connected charging equipment or inductive-wireless charging equipment.

The Society of Automotive Engineers (SAE) Recommended Practice J 1772 [57] covers the general physical, electrical, functional and performance requirements that facilitates conductive charging of EVs. SAE J 1772 , also known as a "J plug", is a North American standard for electrical connectors for electric vehicles maintained by the SAE International. The J 1772-2009 connector is designed for single phase electrical systems with 120 V or 240 V such as those used in North America and Japan.

2.2.1 EV Charging Point Connectors

The EVSE charging point connectors can be broadly classified into two types namely, AC charging and DC charging [6].

The International Electrochemical Commission (IEC) and the Society of Automotive Engineers (SAE) define plug types and power levels of EVSE. The categorizations of charging types are presented in Table 2.3 and Table 2.4.

Table 2.3: Charger types and their technical specifications [6]

Charger Types & Sockets	Picture Socket & Plug		Origin and Popular EV Models	Maximum Power Output and Communication Protocols
AC Chargers				
Type-1 with Yazaki Socket			Japan, USA (uses separate standard – JSAE 1772 due to 110 Voltage)	Up to 7.4 kW (32 Amps, Single Phase)
IEC 62196 Type 2 connector, Mennekes			Europe (Germany) – many European cars	Up to 44 kW (63 Amps, 3 Phase)
Type-3 with Le Grand Socket			France and Italy – some European cars	Up to 22 kW (32 Amps, 3 Phase)

DC Charger Types			
CHAdeMO	 	Origin from Japan; Most popular DC charger in the world; used in Japan, Korea and parts of USA and Europe; Nissan Leaf, Mitsubhi, Kia etc	Up to 400 kW DC charging (1000 Volts, 400 Amps); Control Area Network (CAN) for communication between EV and EVSE
GB/T		Used in China; as well as Bharat Chargers in India; Chinese Vehicles and Mahindra Electric in India	Up to 237.5 kW DC charging (950 Volts x 250 Amps); CAN for communication between EV and EVSE
Tesla Super Charger	 	Tesla has its own supercharger. Tesla also sells adapter for connecting to a CHAdeMO charger	Up to 135 kW DC charging (410 Volt x 330 Amp); CAN for communication between EV and EVSE
SAE Combined Charging System (CCS)	CCS-1:  CCS-2: 	CCS-1 and CCS-2 versions available. Same plug used for both AC and DC charging; Most European Cars - Audi, BMW, Daimler, Ford, GM, Porsche, VW etc	Up to 43 kW AC and up to 400 kW DC (1000 Volt x 400 Amp) Power Line Communication (PLC) for communication between EV and EVSE.

Table 2.4: Current and future power levels of AC and DC fast charging [7]

Connector type	Regions used in 2018	Typical power in 2018	Maximum power in 2018	Proposed power
CHAdeMO	Japan, Europe, North America	50 kW	200 kW, 400 kW	-
CCS Europe	Europe	50 kW	150 kW, 400 kW	-
CCS North America	United States, Canada	50 kW	150 kW, 400 kW	-
GB/T	China	50 kW	237.5 kW	900 kW by 2020 (new plug)
Tesla	Worldwide	125 kW	145 kW	200+ kW (potentially >350 kW no date specified)

The current charging rate limit in power and time for vehicles in the market are represented in Figure 2.6. For example, with 500 kW of maximum acceptance power rate, Tesla model with charge from 20% SoC to full capacity in 9.6 minutes and 48 minutes at maximum acceptance power rate of 100 kW.

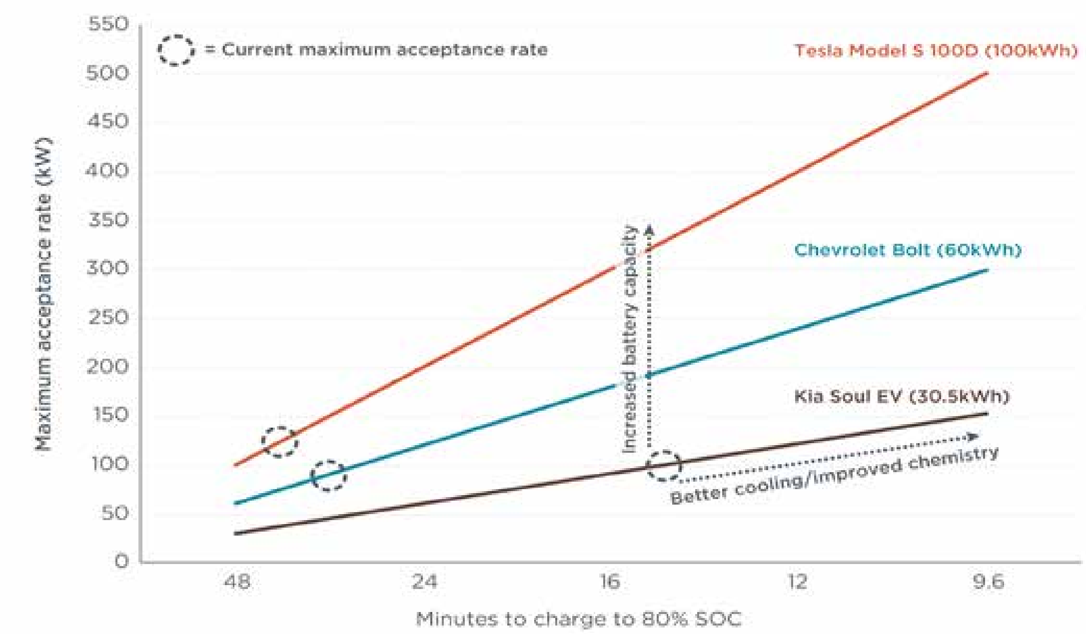


Figure 2.6: Relationship between maximum power acceptance rate of a vehicle versus battery capacity and pack technology with current vehicle examples [7]

Currently, there are major deployments of fast-chargers worldwide owing to an organic rise in the number and location of fast-chargers and also as a result of national plans of respective countries [7]. From the world statistics, it is clear that the charging infrastructure plays an important role to improve the EV penetration. Also, CHAdeMo and GB/T are the most preferred charging port technologies in Japan and China respectively, while CCS dominates in Europe and USA.

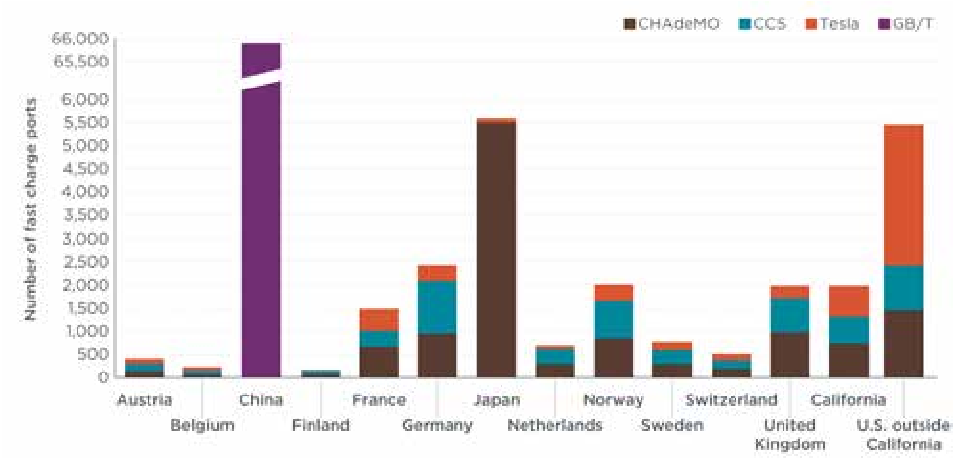


Figure 2.7: Number of fast-charge points in major electric vehicle markets by plug type as of January 1, 2018 [7]

A number of major new fast-charging networks and pilot installations have been announced around the world, providing indications about the future of the E-mobility. Table 2.5 summarizes the plans in major markets around the world, including the number of charging stations, technical specifications, major funders or partners, and timeline [7].

Table 2.5: Characteristics of in-progress fast-charging deployments in leading markets [7]

Network name	Region	Number of fast chargers	Station types	Major partners and funders	Timeline
Electrify America	United States	About 1,800	CHAdeMO, CCS up to 350 kW	Volkswagen	Cycle 1 to be completed in June 2019, with activities continuing until 2027
Ionity	Europe (19 countries)	About 400	CCS up to 350 kW	BMW, Daimler, Ford and Volkswagen with its subsidiaries Audi and Porsche	Under construction through 2020
Trans-Canada	Canada (Ontario and Manitoba)	102	CHAdeMO, ccs	Natural Resources Canada, eCamion, Leclanche, SGEM	In operation by early 2019
Porsche	United States	189 dealership locations	Unknown, 800 volts	Porsche (Volkswagen Group)	Unknown, likely to coincide with launch of Mission-E in 2019
State Grid	China	10,000 locations, 120,000 units	GB/T	State Grid	Completed in 2020, 29,000 stations in 2018

Rapid Charge Points for London	Greater London, UK	300	Unknown	Transport for London	150 by end of 2018, all completed by 2020
Ultra-E	Germany, Netherlands, Belgium, Austria	25 locations, 50-100 chargers	350 kW	Allego, Verbund, Smatrics, Bayern Innovativ, Audi, BMW, Magna, Renault, Hubject, European Union	Completed in 2018
MEGA-E	Central Europe, Scandinavia (20 countries)	322	350 kW	Allego, Fortum Charge & Drive, European Union	Construction from 2018-2025
NEXT-E	Eastern Europe (6 countries)	252	50-350 kW	E.ON, European, Union, MOL Group, PETROL, Nissan, BMW	2018-2020

Conclusions on Charging Connectors

As seen in Table 2.3 and proposed chargers in [35], the following charging connector technologies can be considered for India.

1. For single phase supply, level 1 AC charger, Type-1 with Yazaki Socket which can handle the power capacity up to 7.4 kW (up to 32 A at 230V, 1-Ø).

2. For three phase supply, IEC 62196 Type 2 connector, Mennekes which can handle up to 44 kW (up to 63 A at 415 V, 3- Ø)

3. Combined Charging System (CCS), Type 2 DC connector, CCS-2, which can handle up to 43 kW AC and up to 400 kW DC. EVs with CCS-2 can be used both for AC and DC charging at public/private charging places and work locations. Similarly, with appropriate adaptors (Type 2 AC to Type-1 AC), the same EV can be connected at residential and work locations.

2.3 EV Battery Chargers: Principle of Operation

This section will further elaborate the operation of EV Battery Chargers (EVBC) for both on-board and off-board systems. Internally, system of EVBC will consist of power electronic converters and control systems which control the EV battery charging.

Figure 2.8 shows the general structure of an EVBC. It consists of two power electronic converters: one at grid side and other at battery side and digital control system which is common to both converters [53]. The digital control system is responsible to generate gate pulses to turn the power electronics devices ON/OFF. The gate pulses are generated generally by Pulse Width Modulation (PWM) by using closed loop control algorithm. As discussed in the previous section, an EVBC is called on-board charger when the converters are installed inside the EV and it is called as off-board charger when the converters are installed outside the EV.

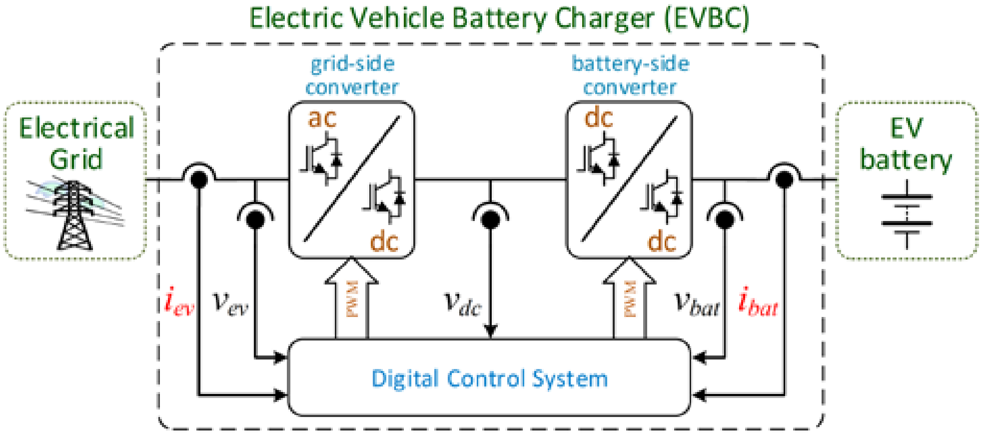


Figure 2.8: Structure of EV Battery Charger (EVBC) with digital control system [53]

The interface of EV with the grid system through an on-board EVBC and an off-board EVBC is shown in Figure 2.9. The power converters in on-board EVBC will ensure the bidirectional power flow between the electrical grid and the EV battery.

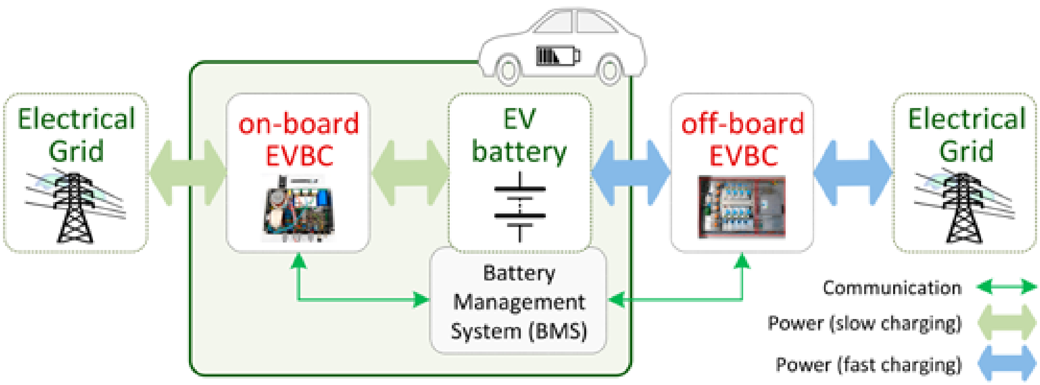


Figure 2.9: Interface of an EV with the power grid through an on-board EVBC and an off-board EVBC [53]

Both on-board and off-board EVBCs use both grid side converter and battery side converter which can be controlled by either current or voltage as per the selected operating mode of the charging system as shown in Figure 2.8. Let's say, constant current mode till SoC (State of Charge) of the battery reaches to 75% and then constant voltage mode till full charge.

The operating mode is defined by specific control algorithms in continuous interaction with Battery Management System (BMS), i.e., the BMS establishes the limits of voltage and current during the charging or discharging processes. Also, due to weight and volume restrictions from the EV perspective, normally on-board EVBCs are designed for lower power ratings than off-board EVBCs. However, in both on-board and off-board EVBCs, the converters isolate the grid and battery. This will indirectly ensure safe operation and reduce operating voltage levels (i.e., the levels between the grid voltage and the EV battery).

2.3.1 Interaction with Grid

The interactions of EVBC with the grid under various operation modes with respect to the type of chargers whether on-board or off-board are presented in Table 2.6.

Table 2.6: EVBC interaction with grid

Operation mode	On-Board Charger	Off-Board Charger
Vehicle to Grid (V2G)	Yes, Figure 2.10	Yes, Figure 2.13
Grid to vehicle (G2V)	Yes, Figure 2.10	Yes, Figure 2.13
Vehicle to Load (V2L)	Yes, Figure 2.11	…
Vehicle to Home (V2H)	Yes, Figure 2.12	…
EVBC as Power Quality Compensator	…	Yes, Figure 2.14
EVBC as Power Quality Compensator with Renewables	…	Yes, Figure 2.15
EVBC as Power Quality Compensator with Renewables and Storage	…	Yes, Figure 2.16

Figure 2.10: On-board EVBC: G2V and V2G operation mode [53]

On-board EVBC in G2V operation mode is the simple and common mode of operation when on-board EVBC is connected with the grid through a smart meter with two way communication as shown in Figure 2.10. Under controlled G2V operation mode, EV battery charging is controlled as per the other connected loads. For example, if total load at home is at the maximum, the EV charging is controlled as minimum and vice versa. In V2G operation mode as shown in Figure 2.10, the stored energy in EV battery will be injected back to grid as per the requirements of the grid management system. Two-way communication with grid operator or grid aggregator is essential to operate the EV in this mode. In both G2V and V2G operation modes, EVBC will absorb or inject the current, where grid-side converter operates with a current feedback control, i.e., the voltage is imposed by the grid and the EVBC defines the current waveform.

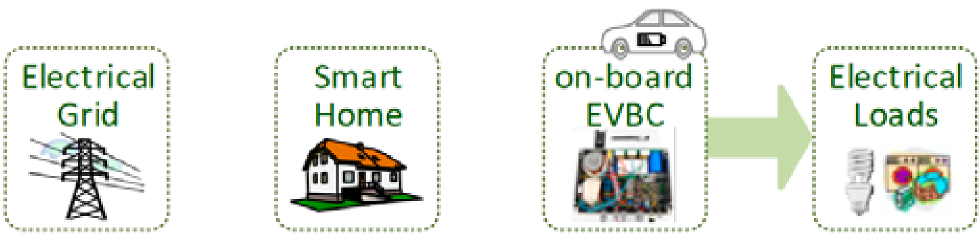


Figure 2.11: On-board EVBC: V2L operation mode [53]

On-Board EVBC in V2L operation mode as shown in Figure 2.11, acts as voltage source. The EVBC operates independently from the grid to provide the power to loads. In this mode, the grid side converter operates with a voltage feedback control.

Figure 2.12: On-board EVBC: V2H operation mode [53]

On-board EVBC in V2H operation mode as shown in Figure 2.12, act as Uninterruptible Power Supply (UPS). In this mode, two-way communications between smart home and EVBC is essential in order to identify a power outage and even to some selected priority loads.

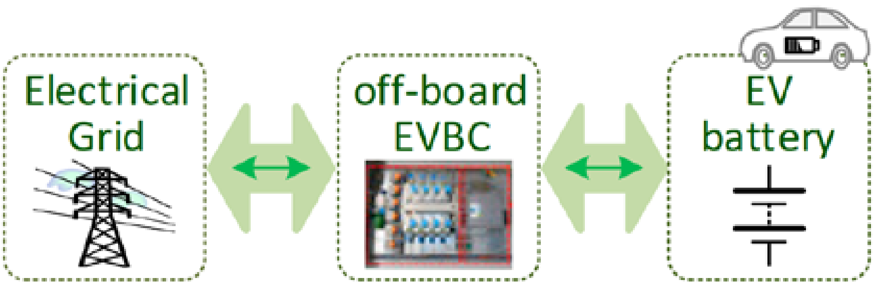


Figure 2.13: Off-board EVBC: G2V and V2G operation mode [53]

Off-board EVBC in G2V and V2G operation modes are similar to on-board EVBC except the power rating of EVBC as shown in Figure 2.13. Bi-directional communication is essential to work off-board EVBC in V2G operation mode. Off-board EVBC used for fleet charging and charging swapping batteries plays an important role in supporting the demand management of the grid by controlling drawal/injection of active power from/to grid respectively.

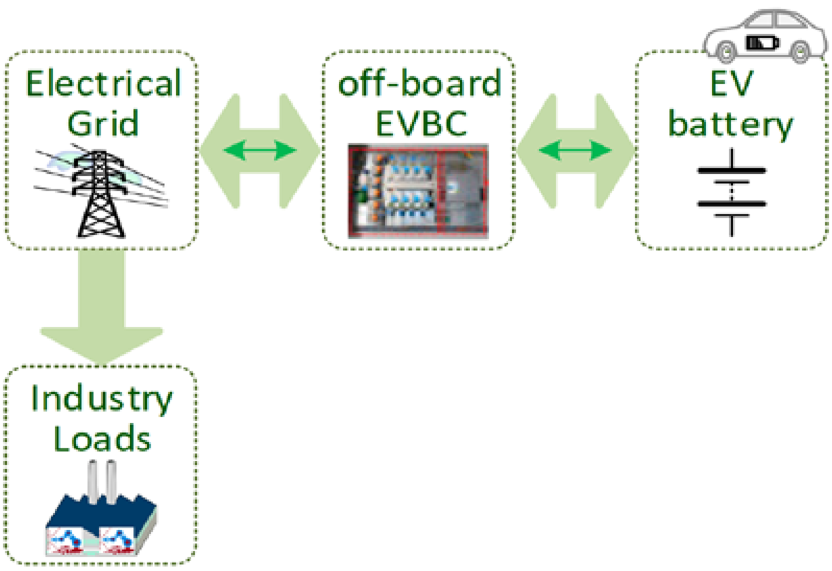


Figure 2.14: Off-board EVBC as Power Quality Compensator [53]

It is also noted that off-board EVBC used in DC fast charging stations may not be in operation when there is nil charging activity. This creates a new opportunity to compensate power quality problems like current harmonics, current imbalances and power factor caused by the non-linear loads in the distribution grid. Off-board EVBC can support the power quality of the grid even it is charging the EV in charging station based on the its rated capacity both in G2V and V2G operation modes. Figure 2.14 shows the connectivity of Off-board EVBC near to industrial loads to compensate the power quality issues.

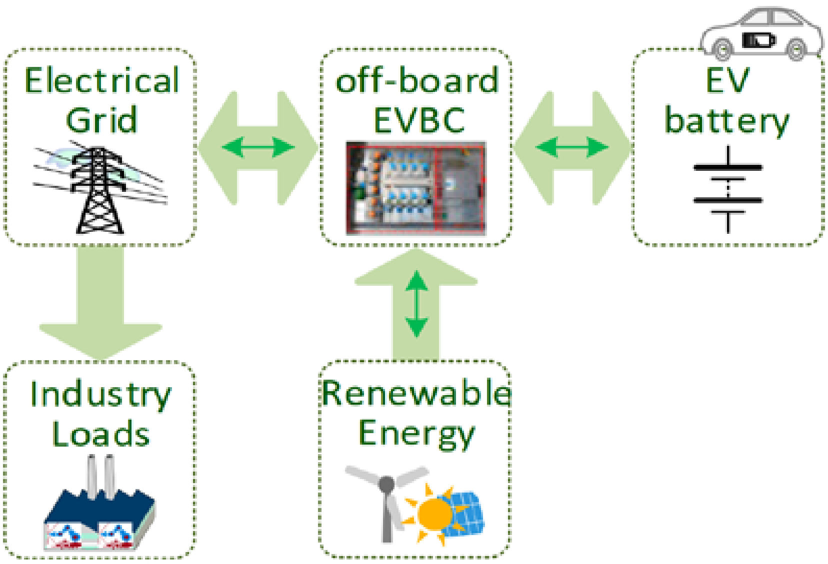


Figure 2.15: Off-board EVBC as power quality compensator with renewables [53]

Off-board EVBC along with solar roof-top generation shares the same grid side converter, in which the EVBC is enabled as power quality compensator that makes the system more robust and reliable in its operation with respect to grid as shown in Figure 2.15. Similarly, an additional battery storage implemented on top of this system is presented in Figure 2.16.

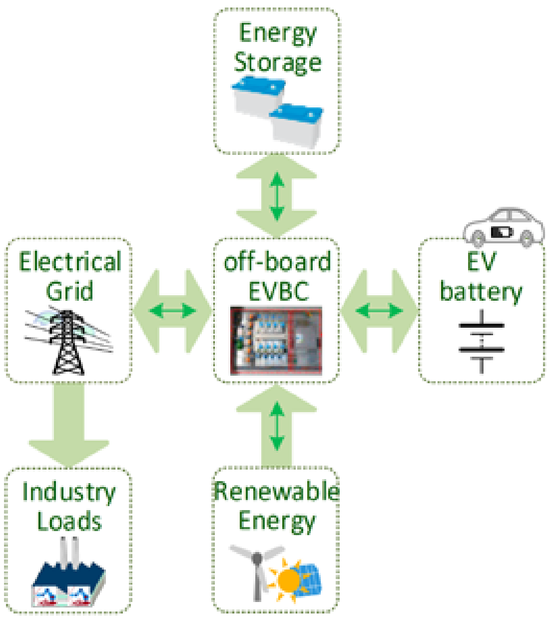


Figure 2.16: Off-board EVBC as power quality compensator with renewables and storage [53]

2.3.2 Power Electronics in Electric Vehicles

In the past decades, power device technology has made a tremendous progress. Among the existing power devices, including the thyristor, Gate Turn-Off thyristor (GTO), power Bipolar-Junction Transistor (BJT), Insulated-Gate Bipolar Transistor (IGBT) etc, the IGBT is almost exclusively used for modern EVs.

Both DC and Ac motors are used in EVs at initial phase. However, the industry focuses more on AC motors in recent times considering the advantages such as, high power rating and long range, less overheating comparing to Dc motor during long drives in spite of its higher cost. AC motor can serve as a generator and bring power back to its batteries. AC motor will handles rougher terrain more effectively and also allows more acceleration.

Figure 2.17 presents the power electronics of internal battery charger with AC motor as a traction motor [53]. It is formed in two stages: AC/DC converter and buck chopper. With the help of relays, the topology is switched from the traction operation to the charging operation.

In the traction operation, the three phase relay connects the converter (connected with battery) with traction motor. In this operation, the converter acts as an inverter and converts the dc power from battery to ac power and supplies to the traction motor to run the EV. In the charging operation, the converter acts as a rectifier and connects with AC charging point and battery, bypassing the traction motor through relay. In both rectifier and inverter, the converter operation will be controlled by IGBT switch ON/OFF gate signal generated by PWM technique. AC filter plays the two-fold role of decoupling the grid from the switched voltage at the input of the PWM rectifier and of reducing the high-frequency current harmonics absorbed by the AC battery charger. The AC filter is aimed at forcing the absorbed current harmonics to meet the IEC 61000-3-12 and IEC 61000-3-2 standards.

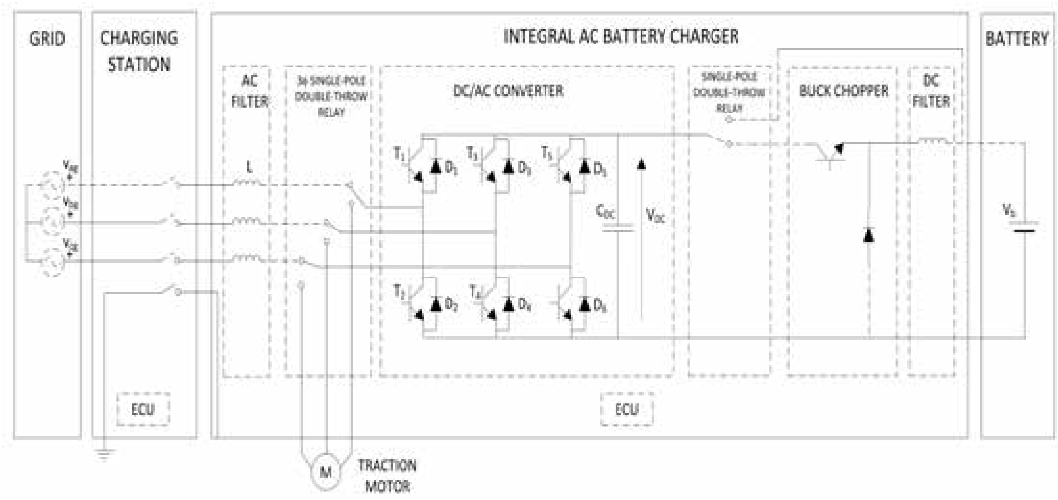
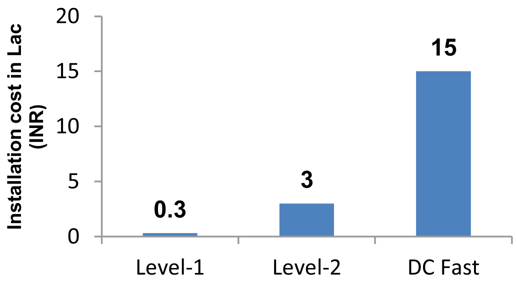


Figure 2.17: Power electronics of an internal battery charger [53]

2.4 Cost Estimation of Charging Infrastructure & Tariff for EV Charging

2.4.1 Cost of Charging Infrastructure

As per India Smart Grid Forum (ISGF), Figure 2.18 shows the cost of installing an EV station in New Delhi estimated for level-1 charger of 1.5kW, level-2 charger of 6.6kW and DC fast charger of 50kW capacity [8].



The cost of charging infrastructure includes the following:

- Fast-charging hardware/equipment cost
- Locational cost
- Installation costs, civil works
- Distribution network costs
- DSO permissions
- Operation and maintenance cost

Figure 2.18: Estimated installation cost of an EV charging station [8]

The tariff rates charged by utilities for fast charging and residential vary widely. However, a standard procedure for tariff determination for EV charging is yet be started by DISCOMs in India. Energy-only rates are available for residential and some commercial customers as well. However, for most commercial and industrial rates, power in kW and energy in kWh (fixed rate for capacity charges and variable rate for energy charges) are often billed individually.

> "The most straightforward alternative rate structure is to simply eliminate demand charges and charge a higher flat rate per kWh. This strategy has been adopted by Southern California Edison for a period of 5 years and system impacts will be reassessed with better data on continuous basis [7].

2.4.1.1 Tariff Structure for Fast Charging Stations

Tariff structure for DC fast charging stations will always a complex exercise for DISCOMs as to determine the true system cost of the electricity use. Alternative rate structures that better reflect overall cost of electricity used have been proposed in various countries.

San Diego Gas and Electric has proposed an approach addressing each of the four cost drivers for the utility grid [10]. First is a basic charge per kWh of electricity, proposed at $0.14/kWh. Second is the generation cost, typically $0.03/kWh. Third is a dynamic adder for the top 150 hours per year of the total grid system peak in kW and an additional $0.51/kWh is assessed. Fourth is a dynamic adder for distribution during the top 200 hours of circuit peak reflecting the stress in the local distribution grid, proposed at $0.19/kWh.

The challenges of low utilization rates and high energy costs are a large barrier to many operators. The following scenario illustrates the relationship between utilization and cost per kWh delivered. This relationship between the number of charging events per month against the effective cost per kWh to serve that event is shown in Figure 2.19 [7].

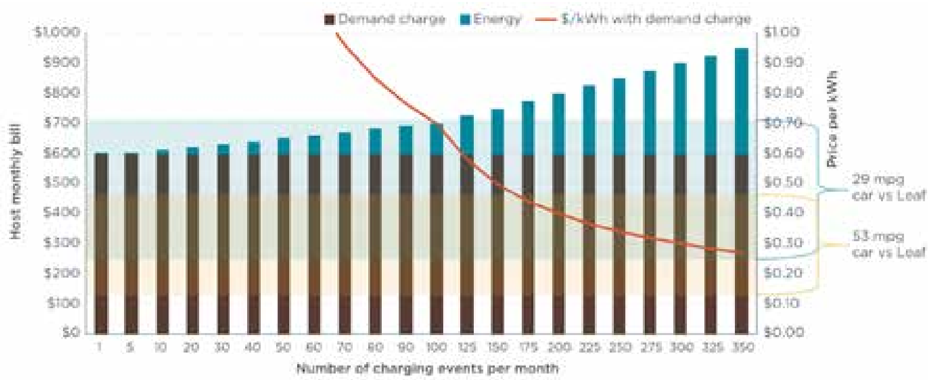


Figure 2.19: Fast-charger host site bill as a function of charge events per month with shaded region showing area of competition with gasoline priced between $1.80 and $7.00 per gallon [7].

Conclusions:

It is difficult to arrive at the real cost of electricity in India owing to the following factors:

a. Electricity tariff based on subsidies

b. Policies decision both at central and state level and

c. Lack of market discovery mechanism

Hence it is difficult to adopt the tariff structure used in 'San Diego Gas and Electric' in India. It is also important to encourage the EV penetration in India at initial phase. Hence, the following tariff structure can be looked into in recent and long-term horizons:

For residential category:

1. Energy based tariff (if required, subsidized) till EV penetration reaches certain level say 10% of total vehicles in India or till 2021 or 2022.
2. Phase out the energy-based tariff by 2021 or 2022 and introduce capacity and energy-based tariff. Capacity based tariff based on connected capacity in kW for EV charging and variable nature energy-based tariff for utilization energy for EV charging. The variable energy tariff is similar to the present tariff structure that exists based on usage limits. It is recommended to have separate meter for EV charging in the future.
3. Introduction of Time of Use (ToU) tariff to minimize the loading on the feeder during peak hours. This can be introduced by 2021 or 2022 or crossing the EV penetration more than 10% of total vehicle sales.

For commercial categories:

1. Two-part tariff that includes the capacity and energy-based tariff. However, at the initial phase subsidized tariff can be introduced to encourage the EV penetration and phased out at a later stage.
2. Introduction of Time of Use (ToU) tariff to minimize the loading on the feeder during the peak hours.

For EV charging stations:

1. Introduction of two-part tariff along with ToU tariff structure.
2. After the initial phase, introduction of smart pricing tariff based on the grid condition which shall enable the charging station operator to look for smart charging technologies thereby, minimizing the impact of DC charging station on grid during peak hours.

2.5 Types of EV Charging Systems and Processes

The following agents will play an important role in EV charging process as per European practices [1].

Type of EV charging agents as per European Practices:

1. EV owner/driver
2. Battery Owners
3. EV charging manager or Charging Point Manager (CPM)
4. EV charging infrastructure owner
5. EV electricity Supplier-Aggregator (EVSA)
6. EV IT service provider

EV owner / driver

Plug-in electric vehicle (EV) owner is the agent that owns an EV and requires electricity to charge its EV battery.

Battery Owners

The primary and high cost component of EV is the battery. Different new business models with different ownership structures needs to be evaluated to lower the entry barrier for the new technology. Battery owners can sell the batteries to vehicles or can operate the charging stations based on battery swapping for EVs.

EV Charging Manager or Charging Point Manager (CPM)

CPM acts as final customer for DISCOM and will buy the electricity to charge EVs under a commercial agreement. Different ways could be possible under CPM:

1. A residential user with EV charging point his/her own use
2. An office user with several EV points in the office parking area for use of its employees
3. A commercial building user with several EV charging points in its parking area for use of its clients
4. An EV charging station owner with several charging points with different charging options, slow/fast charging ports

EV Charging Infrastructure Owner

The EV charging infrastructure owner is similar to CPM with the management of all control functions and not providing the charging service. In some cases, area owner will be different. Hence on private property three possibilities may occur such as area owner, CPM and EV infrastructure owner. On public property, the installation of charging infrastructure can be part of the distribution business, and therefore the owner of this infrastructure would be the DISCOM/DSO.

EV Electricity Supplier-Aggregator (EVSA)

EVSA is the agent who sells the electricity to the EV owner. In some cases DISCOM will be EVSA. EVSA can sell the electricity not limited to one location but multiple outlets or cities. The EV users can charge their EVs at multiple charging locations while remaining with the same EVSA. In this case the EV electricity supplier acting as an aggregator could also play a key role in the future providing V2G services to the Transmission System Operator (TSO).

EV IT Service Provider

IT-service providers could act as the link between the different agents such as EV owner and EV supplier, EV supplier/aggregator and DSO, while connecting all the different players to electricity market, by providing real time and accurate information. IT-service providers could be commercial players that invest in communication infrastructure and tele-connections, maintain the communication network and offer IT services to all the players.

2.5.1 EV Charging Modes & Business Models

Various modes of EV charging processes are possible as presented in Figure 2.20, based on charging location (at home or at public charging etc.) and the charging infrastructure are to be developed as per the EV process business mode.

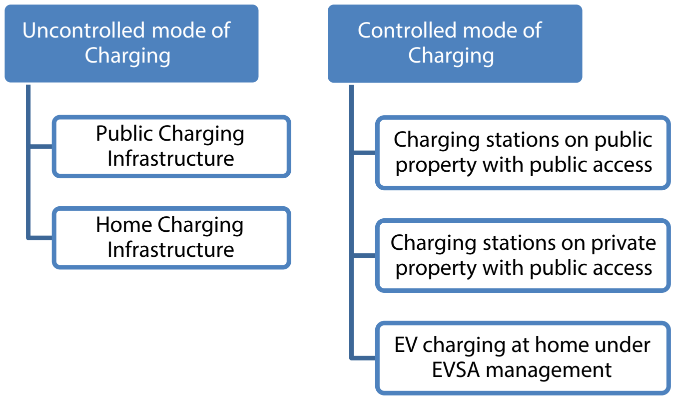


Figure 2.20: Various modes of EV charging processes [1]

2.5.1.1 Uncontrolled Mode of Charging

Public Charging Infrastructure

The functional diagram of charging station infrastructure is presented in Figure 2.21. EV Charging Point (CP) is the connection point between the EV and the charging infrastructure. The Final Customer Meter (FCM) and the utility meter will be installed by Utility DISCOM at customer connection point. FCM measures the energy consumption (kWh) and peak consumption (kW) with time stamping. FCM can collect hourly measurements and include bi-directional communication with the DSO along with control functions.

The EV Meter (EVM) measures the energy consumption, the peak consumption and the period of time when the EV is connected to EV station point for billing purposes. EV meters will also have communication with the EV supplier for billing and remote charging control. The power to the EVs can be supplied from the grid or internal battery storage or any rooftop PV generation with battery storage.

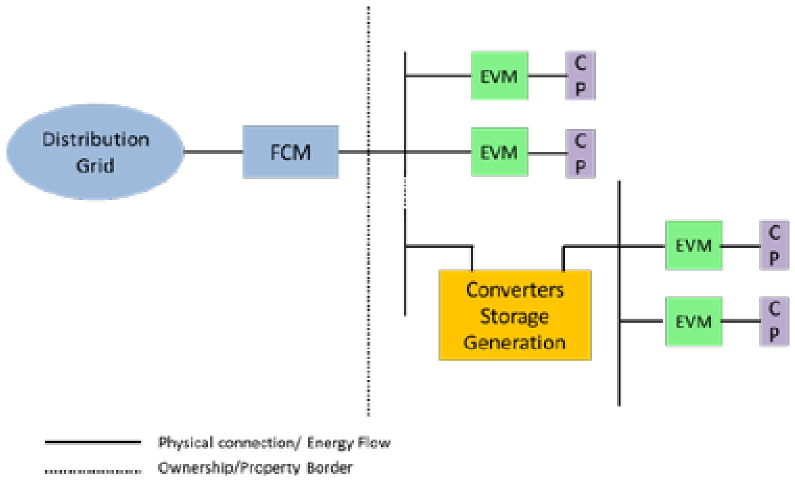


Figure 2.21: Charging station infrastructure [1]

The EV Manager Controller (EMC) is a controller, similar to an energy management system operated by the corresponding CPM or EVSA. A reliable bi-directional communication system should be implemented between the EV manager controller and the on-board EV charge controllers.

On-board EV State of Charge (SoC) indicator, measures the state of charge of the EV battery as a percentage of the full charge or in kWh. An on-board EV charge Controller (EVC) is a programmable controller that provides a menu of alternatives to the EV owner for charging the EV battery during its connection period. It is located inside the EV. On-board EV meters (EVM) provide information about energy consumption, peak consumption and times of connection on request.

EV charging station can also have Battery Energy Storage System (BESS) to manage the charging of EVs at peak time, while drawing minimal or zero power (from internal PV renewable generation) from grid while charging BES at off-peak hours.

Home Charging Infrastructure

Under home charging infrastructure as shown in Figure 2.22, the residential customer will have a contract with DISCOM. The charging of EV can be controlled by DISCOM or EVSA under two scenarios like at Time of Use (ToU) prices, i.e. peak and off-peak prices to promote charging at off-peak hours, or more sophisticated contract with hourly time prices that promotes an integrated management of the EV with the rest of the loads.

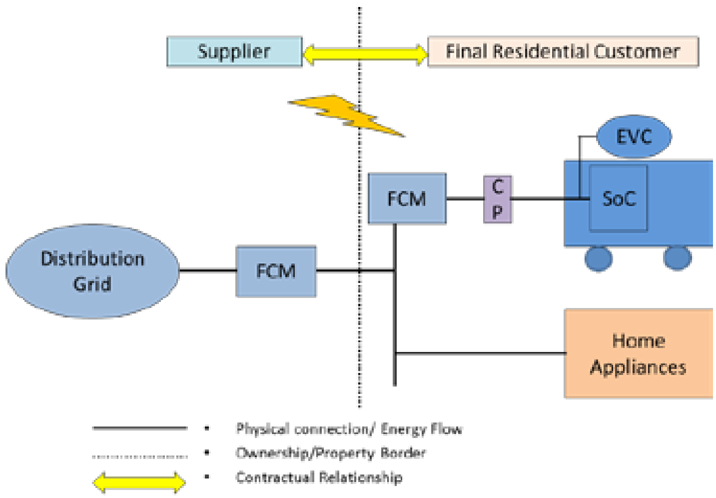


Figure 2.22: EV charged at home with separate meter [1]

2.5.1.2 Controlled Mode of Charging

Charging stations on public property with public access

EV charging stations on public property will be installed by the local DISCOM as part of distribution network in order to have low cost and fast installation of standard chargers as detailed in Figure 2.23. Under this scheme, charging points at EV charging station should be made accessible to any EVSA with neither discrimination nor monopoly practices. EVSAs will sign contracts with EV owners for EV charging. EV owners will pay the electricity bills to the contracted EVSA. The EVSA would pay regulated network charges to the distributor for paying back grid and charging infrastructure costs.

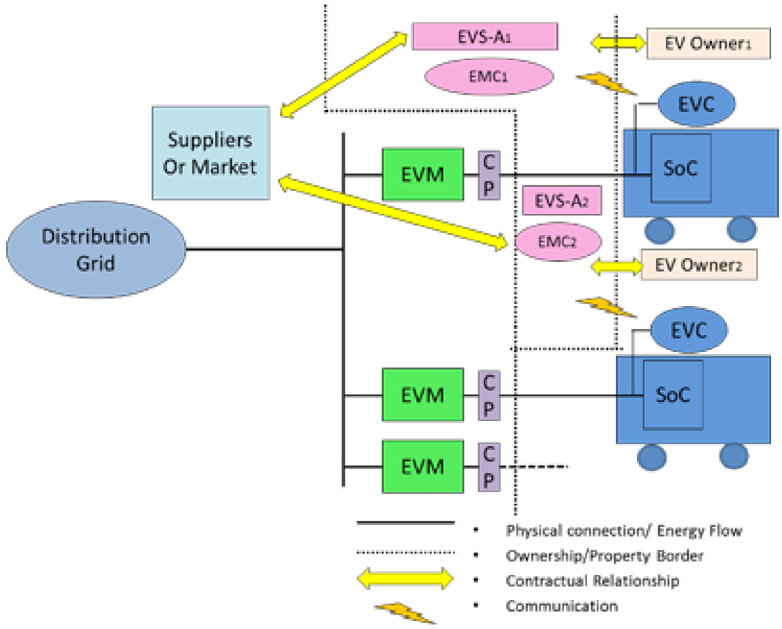


Figure 2.23: Public charging station in control mode of charging [1]

Charging stations on private property with public access

On privately owned property, where vehicle parking access is free, such as corporately operated car parks, shopping facilities, dedicated roadside charging stations and commercial office buildings of various use, the regulatory framework needs to bear unique considerations.

A charging station owner, acting as CPM, installs the required infrastructure. He buys electricity from a supplier and sells EV charging services to EV owners. In this case, the charging infrastructure may include additional equipment (like storage batteries be useful for energy price arbitrage) to convert, store or even produce electricity in order to optimize and diversify the types of charging modes offered to their customers. Finally, the combination of this storage capability with local generation sources like renewable energy can provide additional profits for this business. Figure 2.24 represents this charging business model schematically.

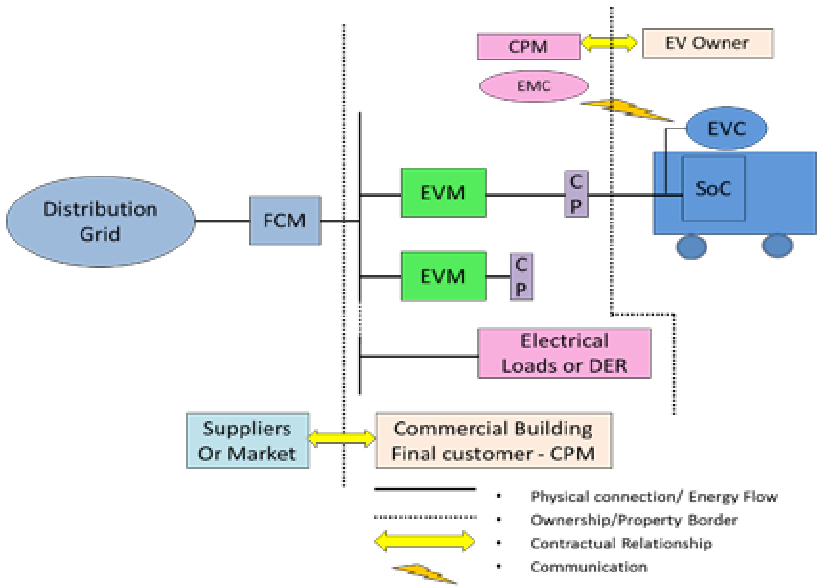


Figure 2.24: Privately owned charging station offering special services [1]

EV charge at home under EVSA management:

In this model as shown in Figure 2.25 EVSA acts as an intermediate agent that buys energy from a supplier or participates in the market while reselling this energy to EV owners who are managed under a charging contract. The EVSA could conduct an integrated energy optimization by aggregating several charging points at the residential level additional to the EV contracts associated with public charging points. This scheme allows separate pricing of energy consumed at home for transportation purposes and therefore, it allows including specific taxes or special rates.

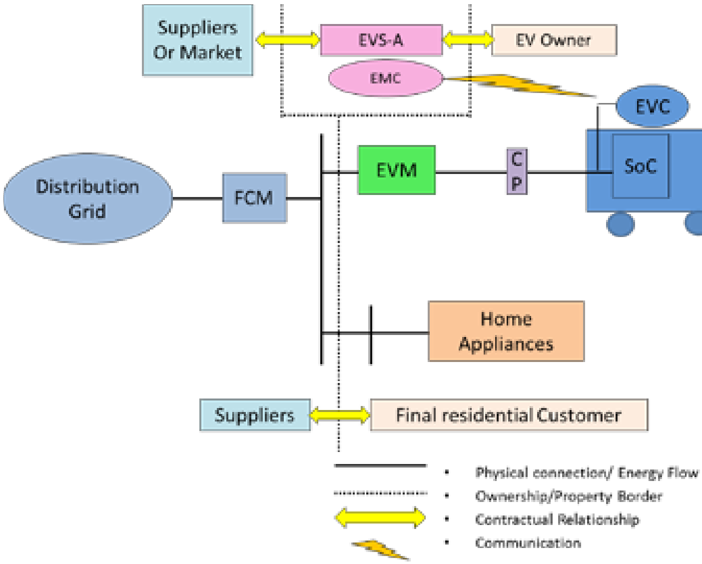


Figure 2.25: EV home charge under EVS-A management [1]

2.5.2 Battery Swapping Stations

The basic swapping approach is simple, in that the user can quickly replace a discharged battery with a fully-charged new battery in less than two minutes. The massive EV deployment will require specialized activities around battery ownership and operation, as battery's cost contributes to a major component in EVs total cost. The main hurdle for such business models is that, there is a lack of standardization of batteries including their interfaces with the vehicles currently.

A swapping station with number of batteries in stock and demand for battery like for 3 wheelers will manage in optimizing the charge of these batteries. The swapping station owner would have the opportunity to optimize the interface to the grid by scheduling the charges at the time duration that are economically favourable. Hence, the best feature of battery swapping is its ultimate convenience and overall pricing.

The battery-swapping operation involving charging and swapping, payment for different services and performance monitoring is quite complex. This is simplified by the digitalization of the whole process assisted by mobile telephony. The Energy Operator (EO) similar to EVSA would charge the leased battery based on kilowatt-hour paid or control the usage as per prepaid amount. Locked smart batteries can be designed where a battery cannot be charged except by an EO-authorized charger and can be discharged only by the vehicle for which it is leased.

Further the charge control mechanism works to manage how the battery is loaded like loading of EV vehicle, speed and acceleration. Under violations of any of these parameters, the battery will stop working based on the remote control signals. It also stores information concerning the battery's state of charge, the state of balance of cells and the temperature of each cell.

A vehicle-to-battery protocol is defined to enable this as well as the authentication. Similarly, a battery-to-charger communication protocol is defined. After authentication the charger picks up all the stored information from the battery and sends it to the cloud. While charging the battery, it also receives information on cell balance, cell voltage and currents and temperature. There is an option of adding a global positioning system to the vehicle and recording the positioning information in the cloud. All these data are then processed to determine an individual's driving habits, the vehicle's performance (especially its energy efficiency), and the battery behaviour during charging and discharging. This will help to ensure that the battery is used optimally and has a longer life.

2.5.3 Software Environment at Charging Station, DISCOM Control Centre and Consumer

While applying appropriate EV charging strategies in the context of demand side management on the electricity grid, the EVs could contribute to better usage of renewable electricity production. For example, EVs shall be charged when renewables production is available and re-inject power to the grid (in the case of future V2G scenarios) when renewables are not available. The adequate management of EV electricity consumption (or injection) can therefore contribute to the development of renewables in the electricity system and to the reduction of renewable energy spillage [1].

The EV aggregator will optimize the EV resources as storage that can be charged in some periods and discharged in others subjecting to driving constraints imposed by EV owners. In addition, he/she could subscribe to specific contracts with an Independent System Operator (ISO) to provide regulation reserves, to buy or sell energy in real-time or day-ahead markets.

In all of these V2G cases, the EVSA remains the intermediate agent bridging the gap between final EV users and the electric power system procuring the required energy demand and offering remunerated ancillary services based on load reductions, power injections and regulation energy for power/frequency control. The interaction between the aggregated EVs and the electricity market is illustrated by Figure 2.26.

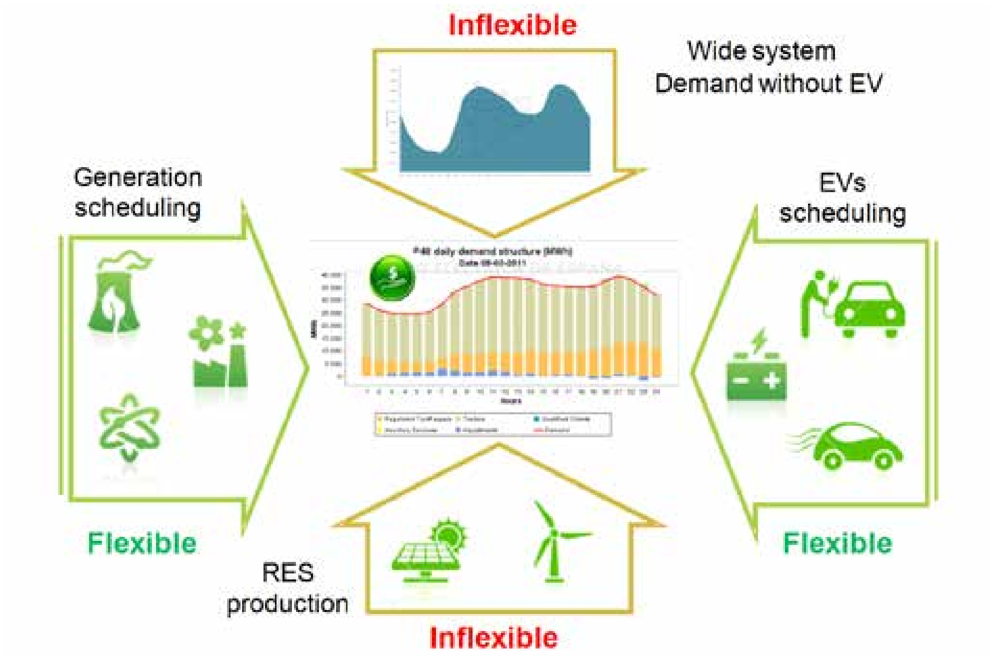


Figure 2.26: Interaction between the aggregated EVs and the electricity market- based on [14]

The summary of Issues and opportunities of various stakeholders under V2G operation is summarised in Table 2.7.

Table 2.7: Summary of threats and opportunities for the supplier, CPM & aggregator [1]

	Electricity Supplier Aggregator (SA)	Charging point manager (CPM)	EV Supplier Aggregator (EVS-A)
Threats	Lack of control	Strict financial liability requirements	High uncertainty: Availability forecast deviations
	Increased demand volatility	False long-term load forecasts to recover equipment costs	High risk exposure to market price volatility
	Added uncertainty: Forecasting becomes more difficult	Over-complicated regulations as reselling entities	Under/overestimation of battery degradation costs
Opportunities	Additional load	Extension of other business to the offer of charging services	Management of high energy demand per customer
	Turnover increase	Turnover increase by electricity trading	Highly flexible and schedulable load
	Increase in demand flexibility	Simple regulatory framework easing the offer of charging services	Valuation of network investment deferral
	Demand response to price signals	Offering charging services attracts clients for other business	V2G prospects for participation in ancillary service markets

The V2G charging modes pose an interesting challenge to the regulation of network usage and compensation similar to the one presented by high penetration of distributed generation on the grid. Regulation should be acknowledged by properly regulated network charges paid by EVSA, the costs incurred by DSOs due to variation of power flows, decrease in total energy delivered and increase in losses as well as the benefits incurred due to the deferral of investments related to network reinforcement.

Conclusions on Types of EV charging systems and processes

The revenue generated solely from the power sales to EV drivers that charge their vehicles in EV charging infrastructure observed in Europe and USA is not sufficient to recover the investment in the infrastructure.

Some charging service providers, such as 'Charge Point in the US' and 'The New Motion in Europe', have followed a different approach. They provide both the hardware (i.e., actual charging stations) and back-office services (such as payment and billing services) as a turnkey solution for customers who want to have charging stations installed, such as retailers, municipalities and businesses with parking lots for their guests and employees. EV drivers pay for a subscription with the service provider and – with the use of an identification card – can get access to the network of all publicly accessible stations connected to the network. This can work similar to mobile service providers with subscriptions and roaming facilities among various service providers.

The improvement of the charging infrastructure is a critical catalyst to scale-up the EV adoption. Considering the various business models in other countries, the following several services and business models can be applied in India to improve EV penetration:

1. Maintaining charging infrastructure - Similar to operating petrol stations, there might be a business case in operating charging infrastructure – for example, operating a fast-charger highway network in combination with retail activities.
2. Charging services (payment, access and registration) - In order to charge at a charging station, the customers can have access card or account with an EV charging service provider. This service provider operates a back-office with payment and billing systems, so that the customer gets billed for the electricity that is being charged into the car.
3. Charging point services (installation and maintenance) - Any service companies on the market can participate in erecting charging point services for private charging. They install charging points at home or at the office and provide maintenance services.
4. Navigation software and apps related to charging infrastructure - Since EV infrastructure is still not widely available, in the near future, EV drivers need to actively seek out not just the location of charging stations in maps but also the type of station compatible with their vehicle. In the future, this may lead to making a reservation for a charging station slot as an additional functionality.

2.5.4 Grid Infrastructure Required for EV Charging Stations

The integration of EVs with energy systems require many layers of systems that interact and exchange information. This means it requires data and technology integration services as well as applications utilizing such integration along with contractual components, thereby impacting the financial aspects of services and markets. This integration is also an important pursuit in the web of development for the Internet of Things (IoT) and smart cities, as billions of devices are integrated through cloud, fog and other edge computing approaches [4].

The use of ICT (Information and Communication Infrastructure and Technology) and appropriate communication infrastructure is necessary for a successful deployment of EVs at different levels with varied requirements. It permits and/or supports the activities of the different stakeholders involved in EVs market (including the users), for instance consider the following:

- Data collection and processing, e.g. for metering and billing
- Automation and control of the grid
- Implementation of demand management strategies or of V2G capability and the aggregation of EV consumption flexibilities
- Provision of information services to EV drivers
- Possibly EV remote maintenance
- EV fleet management etc.,

On the grid side, the impact of the EVs on the network has to be considered and measures have to be taken to mitigate the possible constraints. The current and future innovations and new concepts developing in the context of smart grids provide a favourable environment for the development of EVs. The following can be listed among others:

- Deployment of smart meters and the associated communication infrastructure
- Increased observability and advanced functions for distribution grids operation, grid automation and control
- Active demand management concepts and technological solutions for the implementation of smart strategies for EV charging and V2G in the future

- Increased penetration of DG, RES and storage and their full integration in the electricity system as active components that to provide services and additional flexibility to the electricity system
- The development of intelligent home energy management systems to control the electric appliances at the consumers' premises, which can be adapted to the control of EV charging and discharging.

The role of DISCOM in deployment of public charging infrastructure is summarised in Figure 2.27.

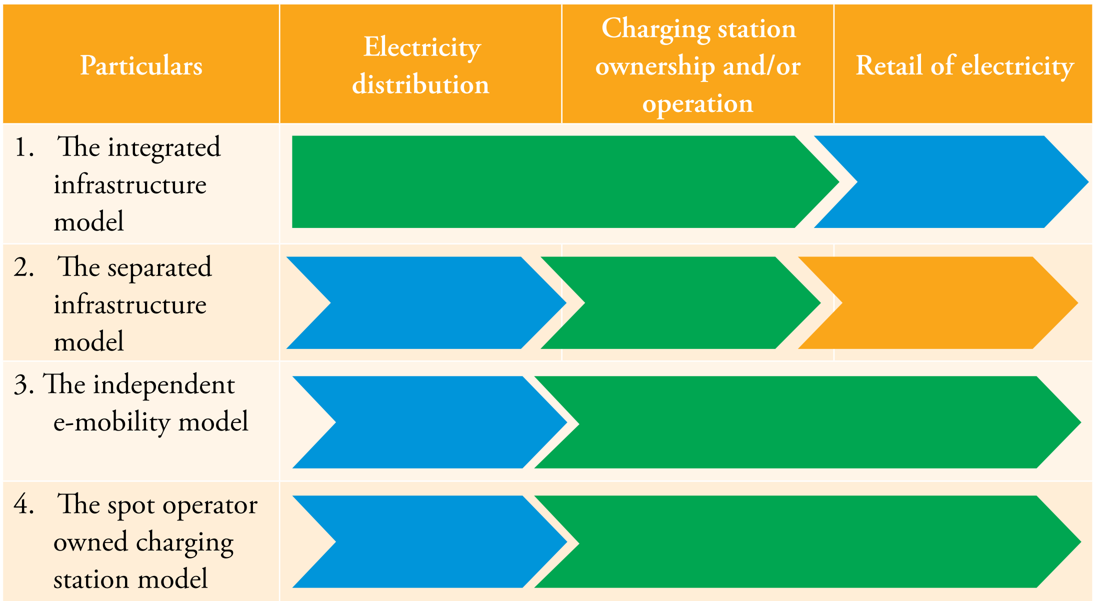


Figure 2.27: Market models for the development of public charging infrastructure [13]

03

Impacts of EV Charging on the Grid

Integration of EV, charging of large fleets connected to low voltage networks will impact the power system planning and operation. The impacts of these new loads, which were not considered at the electricity system planning stage, will be spread through the electricity system and will be highly dependent on local factors such as EVs penetration, energy mix, grid topology and driving patterns of the EVs' owners among others. Figure 3.1 shows different technical aspects at various power system levels.

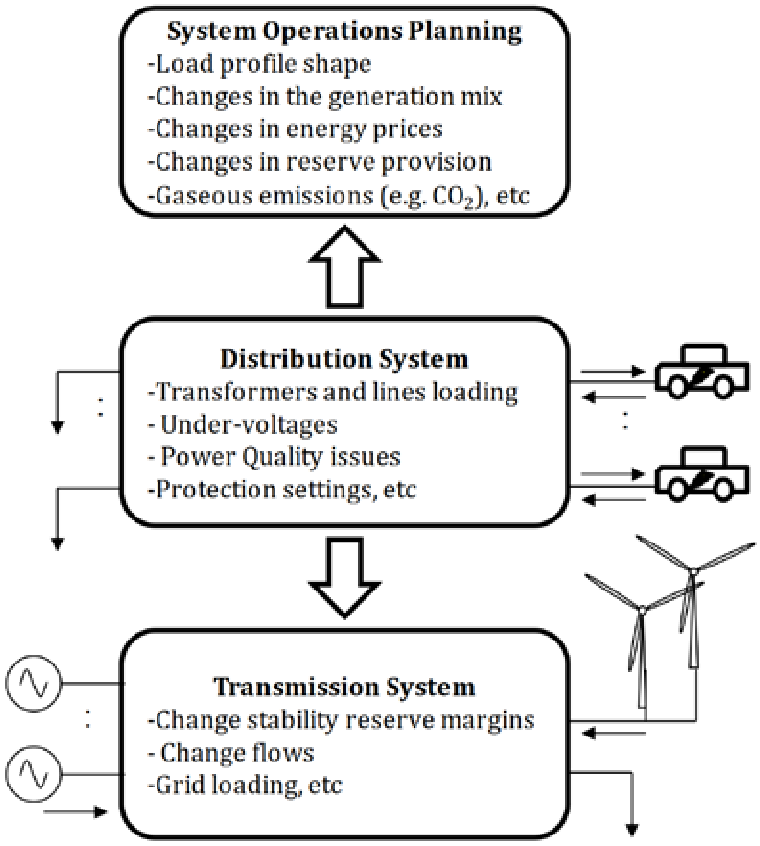


Figure 3.1: Potential impacts on the power system due to the integration of EVs [15]

The impacts of EV flexibility on power system planning and operation is presented in Figure 3.2.

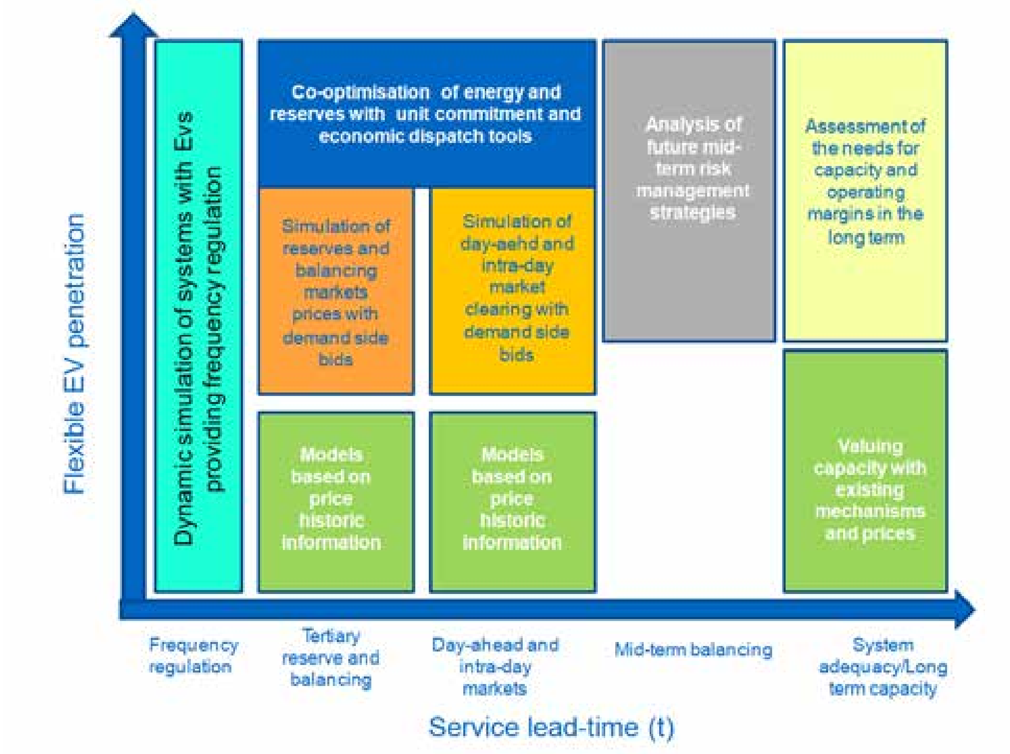


Figure 3.2: Models for flexibility valuation for different penetrations of flexible EV [1]

Issues and opportunities for DISCOMs as a result of the adoption of EVs are presented in Table 3.1.

Table 3.1: Summary of threats and opportunities for the DSO [1]

DISCOM Issues	
Network Planning	• It is more complicated to forecast the future load growth including EVs. Grid reinforcements which may not be included in the allowed revenues could be required. • If DSOs are responsible for developing charging infrastructure, these are high-risk investments unless regulation ensures cost recovery. Otherwise, the development of parallel networks could take place.
Grid operation	• With increase in EV penetration in the distribution system, the power drawn by the system will be more, which in turn requires additional system infrastructure to be developed by the DISCOM. • Uncoordinated EV charging may cause excessive voltage drops in heavily loaded lines, particularly in long radial networks. • EV inverters, which covert the power from DC to AC, may create power quality problems, e.g. harmonics. • Relying on EVs to provide system services poses certain risks of non-compliance which should be managed and shared by the DISCOM and EVS-A/CPM.

Metering	• Smart meters currently deployed will need to cope with EVs. • If dedicated meters are required to separate EV charging from other electricity consumption, a significant roll-out of new meters would be required. The extent will depend on the market models implemented. • The role of DISCOMs and how to finance the costs of the deployment of new meters should be determined by regulation.
Tariff setting	• Lack of freedom to design cost reflective distribution charges that could send efficient economic incentives. • Energy tariffs could distort the incentives provided by distribution charges. This can create problems in some distribution areas.

DISCOM Opportunities

- An increase in the amount of energy distributed could constitute an increase in the DISCOM revenues under some regulatory frameworks where revenues are not decoupled from energy delivered.
- Local voltage and reactive power control are possible by EV inverters. This is particularly relevant to car parks and dedicated charging stations connected MV networks.
- EV charging can compensate for high DG production during valley hours (typically at night), thus allowing DISCOMs to alleviate congestions and reduce or defer grid reinforcements.
- The equipment and ICT deployed for demand side management could be applied for the control and coordination of EVs, thus providing added value to these investments.
- EVs will increase the volume of load that can be controlled, thus creating an added driver for the implementation of demand side management.
- New services related with power flow control at distribution level could be offered by EVSA which could serve as a substitute of conventional operational practices to minimize interruptions, manage congestions or plan maintenance actions.
- Large EVSA can communicate with a DISCOM control centre and provide services such as load forecasting, thus facilitating grid operation.

3.1 Impact on the Power Network

Uncontrolled EV charging can cause a range of power network problems including voltage limit violations, component overloads, power system losses, phase imbalance and issues with power quality. However, the level of impact depends not only on EV variables, such as adoption rate and level of charging, but also on circuit-specific characteristics, such as topology and existing loading.

- Thermal loading → to what extent component is normal and emergency ratings exceeded (number of occurrences, typically overload asset classes, duration and magnitudes)
- Voltage → to what extent does EV loading adversely impact system voltage regulation. (Voltage excursions, regulator operations, cap operations, etc.)
- Unbalance → potential for disproportionate penetration on particular phase and results on system unbalance
- Losses →impact on distribution system losses

3.1.1 Component Overload

Amongst other criteria, expected load and temperature are key parameters used to size the power network components. Low voltage (LV) feeders and distribution transformers are most sensitive to overloading from EV clusters as these components do not benefit from spatial diversity. Transformers can be safely overloaded for short durations; however, the transformer life would be reduced if the operation is not balanced with extended periods below the load rating. An exponential relationship exists between aging and the winding hot spot temperature. Factors affecting hot spot temperature include loading and ambient temperature.

Studies in this area mainly involve distribution transformers in the United States of America (USA), which commonly have a rating of 25 kVA. Results show that uncontrolled charging can have a considerable impact on transformer aging, with the study showing an expected transformer life of 6.7 years with two EVs charging, based on a typical life of 20.55 years [17]. The charging of a single EV will have less of an impact on European distribution transformers, which typically have higher ratings up to 1000 kVA. The EV impact is dependent on the percentage increase in loading, relative to the load rating. Similar sensitivity results could be expected, such as the large impact on aging with higher charging rates and high numbers of EV charging [18].

3.1.2 Voltage Control

Battery charging of EV will increase the power demand in distribution networks. It is anticipated that a high EV uptake will cause significant voltage drops on distribution feeders [16].

The two types of voltage control that can be achieved are the following:

1. Local voltage control
2. Coordinated voltage control

Local voltage control is the easiest method to implement when voltage control is required. Depending on the type of grid, the voltage control actions are processed differently from the conventional techniques. In these networks, reactive power control is not sufficient to maintain efficient system operation, especially in LV networks where the X/R index is low. (X/R ratio is the ratio of the system reactance (X) to the system resistance (R), looking back to the power source from any point in a power circuit, assuming that a short circuit is applied to the system at that point. It is a way of stating the power factor of the source system. It should be noted that this is the power factor of the system up to that point and has absolutely no relationship to the power factor of any load on the system. Since generators, transformers and transmission lines are generally quite highly inductive, the X/R ratio is generally significantly above unity). If voltage sags occur, it has been shown that they cannot be corrected efficiently by injecting reactive power. In the present case, it is more efficient to reduce the load or inject active power. Therefore, the local control action is based on a droop that controls active power according to voltage deviations that may result from normal or abnormal operation of the grid.

Figure 3.3 shows a possible implementation of a droop control for voltage. This dead zone is expected to be between 0.9 and 1.1 p.u., whereas in weaker systems it will be from 0.95 to 1.05 p.u.

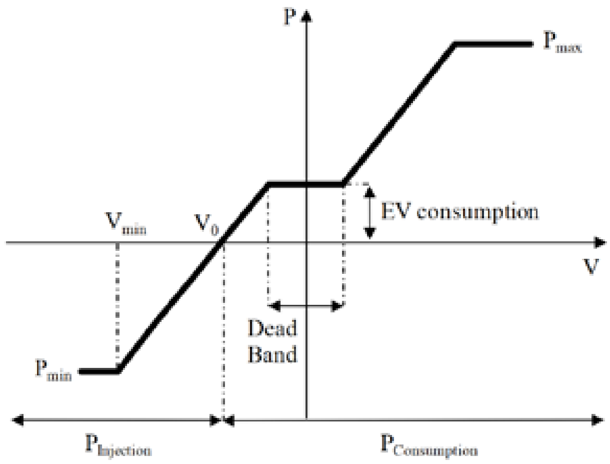


Figure 3.3: Voltage control droop for EV [16]

In coordinated voltage control DISCOM/DSO will follow the procedure based on the data gathered for voltage control logic. The EV data required for coordinated voltage control is presented in Table 3.2, comprising charging point related data and the EV owner preferences data. Once again, EV owners willing to participate should be remunerated for the service they are providing.

Charging Point Related Data	Customer Preferences Data
Charging point Identification Number (ID) → Network location; Maximum charging rate	✓ Charging mode ✓ Actual SOC of EV battery ✓ Connection duration ✓ Desired SOC at the end of the connection duration

Table 3.2: EV related data required for coordinated voltage control [16]

3.1.3 Voltage Limit Violation

During the starting of EV charging, high inrush current will be drawn for few milliseconds. If this exceeds the limits prescribed by Distribution System Operator (DSO), the manufacturers will be responsible for such issues and if this causes deviation in voltage level, the DISCOM/DSO can demand for a soft starter to resolve these voltage issues.

Owing to power electronics devices, current harmonics will be introduced into the system and if the grid impedance is high enough, the harmonics will affect the grid voltage which may lead harmonic violations in the grid [19].

Study [20] showed that when EVs are connected closest to the substation, a penetration level of 42% can be accommodated without voltage limit violations occurring at the customer at the end of the feeder, compared to 28% when EVs are connected at households furthest from the substation

The increased power demand from EV charging causes the voltages on the medium voltage (MV) and LV network to decrease, where the voltage drop is proportional to the load. The impact of EVs on voltage drop is more significant on the LV network, since On-Load Tap Changers (OLTC) are not usually used on the transformers stepping down to LV. Longer feeder lengths result in larger voltage drops, so it is likely that the most severe voltage limit violations will occur on rural networks, in particular for customers farthest from the transformer. Along with the location of the customer, the location of the EV connection points is also significant.

As per Delhi Electricity Regulatory Commission (DERC) regulations [45] , the acceptable voltage regulations are as follows.

- ±6% for LT network, 230 V Ph-neutral, 400 V L-L
- +6 to -9% for HT network, 11 kV
- +10% to -12.6% for 33kV or 66 kV networks

3.1.4 Reactive Power Issues

As the energy stored in the battery is in the form of DC, conversion has to take place from AC to DC through AC-DC converter. The general rule for converters is that the power factor shouldn't be less than 0.95 to avoid inefficient reactive power flows. Lesser the power factor higher the reactive power flow. Reactive power flow in the line has to be limited as it burdens the grid by raising the total current of the system. The increased current translates into higher heat losses thereby affects the lifespan of the assets [19].

3.1.5 Power System Losses

The variable component of power system losses increases with EV charging, due to increased load requirements. The period of peak load is significant, as variable losses are proportional to the square of current. This non-linear relationship means that the losses due to high market EV adoption rates could become an important issue for power network operators. Studies in this area focus on the impact of increasing EV penetration. In a particular study, the daily energy losses increased by 140% with 50% EV penetration [21]. Although not investigated in the reviewed studies, feeder length and phase imbalance also affect power system losses.

Total Harmonic Distortion (THD) values of 0.18% for a PWM charger, compared to 28.16% for a charger based on thyristor rectification [24]. This distortion can be reduced further by the use of filters. Also, the manufacturers claim that their chargers have sine-wave current draw and unity power factor [23]. The charging of EVs with PWM chargers will not cause power quality problems under normal operation, even with high charge rates and high numbers of EVs.

3.1.6 Power Quality

EV battery chargers use power electronic devices to convert AC to DC power. This conversion process can cause voltage and current harmonic distortion. During the charging period, the EV charge controller moves through different charging phases and during this the Total Harmonic Distortion (THD) of the current drawn by EV will change as a function of time. The distortion will increase if multiple EVs are connected to the same feeder [22].

a. **Effect of Harmonics on Distribution Assets [22]:**

The chargers that are used have power electronic devices that introduce harmonics in to the system. These harmonics have impact on the distribution assets like transformers, cables and protection devices etc.,

i. **Transformers**

Power transformers will be affected by current harmonics as these higher order currents flow within the transformer winding which results in higher I^2R losses which increases the active power consumption and thereby decreasing the efficiency.

Due to increased harmonics, eddy current losses will increase which in turn creates abnormal temperature rise in the transformer windings, which accelerates loss of insulation and ultimately leads to reduced lifespan of the transformer.

ii. **Power Cables**

Because of harmonics, I^2R losses will increase which results in increased heating of the conductor. Harmonics can also attribute to skin and proximity effect which depends on sizing and spacing of conductor and also varies as a function of frequency. Also, cables involved in system resonance may be subjected to voltage stress and corona, which can lead to dielectric failure.

iii. **Relays, Switchgear and Metering Equipment**

Because of harmonics, relays may result in unexpected operation because of high pick-up values. Also, I^2R losses will increase which increases the heating and because of this, the fuses may result in premature operation. Because of increased I^2R losses, the heating in CTs and PTs will increase, which may lead to core saturation thereby shortening the lifespan of the asset.

iv. **Capacitors**

Harmonics will have an impact on capacitors if the harmonic frequency is in resonance with the LC time constant. At resonating frequencies, if the negative reactance of capacitor banks is coupled with the positive reactance of distribution cables, transformers and loads, results in very high voltages and currents. Within resonating capacitors, the unexpected raise in voltage and heating because of I^2R losses result in shortened lifespan.

3.1.7 Voltage Flicker

Voltage flicker can occur when EV charger is connected or disconnected (in response to charging EV) faster than the remaining generators in the grid which can compensate the variation. This leads to voltage excursions that can become noticeable to customers as light flicker or variable motor speed performance. These variations can also wear down equipment that attempts to hold the voltage at a constant level.

> The voltage imbalance can be mitigated by use of symmetrical three phase charging of EVs or by using phase selectors [19].

3.1.8 System Imbalance

Owing to charging of EVs from single-phase supplies (households), a system imbalance occurs during which, there will be difference in voltage and current in one phase compared to another. The system imbalance creates zero sequence components. This adds up to the neutral line in star connected system or circulate in case of delta connected system which leads to conductor heating [22].

3.2 Mitigation of Impacts of Electric Vehicle Charging

As outlined in the previous section, transformer and distribution upgrades are the most likely impacts to the grid from charging installations. These impacts can be mitigated with several strategies including choosing locations with low grid impacts, smart charging and combining fast charging with energy storage. The possible mitigation measures are the following:

3.2.1 Load-Shifting Using Time of Use (TOU) Tariff

Shifting demand from peak moment (e.g., working day afternoon or evening peak) to lower-demand periods (e.g., night) could be accomplished by imposing the different tariff during peak and off-peak time periods and could be an important step in minimizing the impact or even improving management of existing peak demand for electricity.

3.2.2 Specific Network Mitigation Measures

Network reinforcement can reduce component overloads by increasing the load rating of components that are likely to be overloaded. Potential solutions to voltage limit violations, currently being assessed, include in-line voltage regulators and distribution transformer on-load tap changers. Selection of location for fast charging will play an important role in network or transformers upgrades.

3.2.3 Charging Control Strategies

Varying the time of EV charging can alter the quantum of power system losses as well as the number of overloaded components and voltage limit violations. Several charging management strategies exist, with the simplest being dual tariff. Smart charging is a more advanced strategy than dual tariff, involving the active management of EV chargers. Specific chargers are instructed by the utility or by a third-party aggregator to begin and end charging or to limit their charge rate. By actively monitoring the network, the charging of EVs can be controlled in real-time, so that voltage limit violations and component overloads do not occur. The smart charging strategy for illustration purpose is presented in Figure 3.4 for reference.

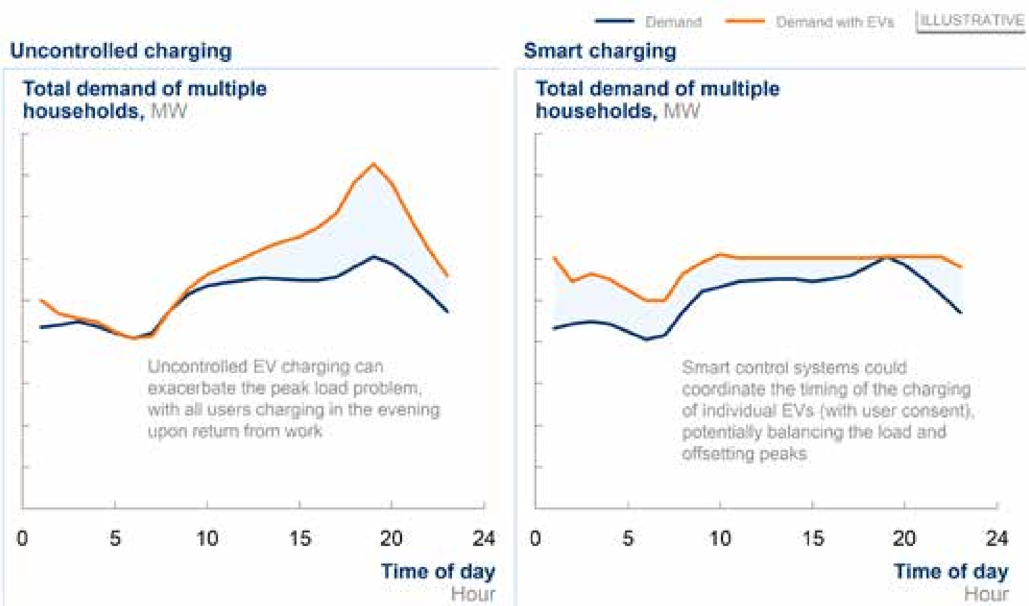


Figure 3.4: Smart Charging of EVs [59]

3.2.4 Usage of Battery Energy Storage Systems

Ref [25] discusses the mitigation measures of harmonics with Battery Energy Storage Systems (BES) in design stage of DC fast charging stations for EV's. It also proposes the optimal size of BES to reduce the negative impacts on the grid by using an energy storage system within the DC fast charging station and is shown in Figure 3.5. The proposed system reduces the charging time and the impact on low voltage grid. In this, two identical battery energy storage systems are used to form a DC fast charging station.

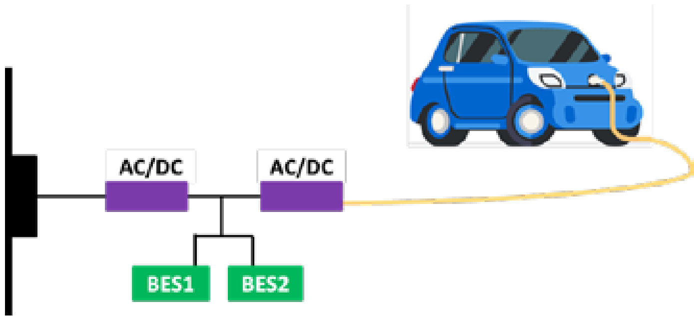


Figure 3.5: DC fast charging station with BESs [25]

The schematic representation of the charging station is shown in Figure 3.6. It depends on the successive switching of BES connections such that one BES will be charged from the grid while the other charges the EV connected to the charger.

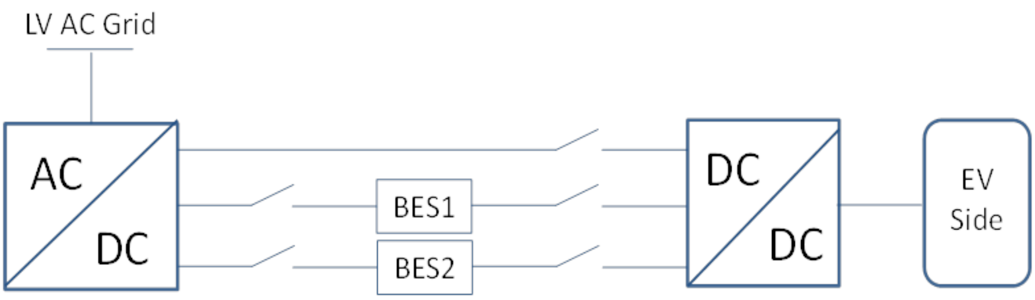


Figure 3.6: DC fast charging station in LV grid with BES [25]

The BES-1 and BES-2 will be charged from the grid even if the EV is not connected to the charger. Once the EV is connected to the charger, one of the BES will provide the supply to the battery in the vehicle and the other will be in isolation. In case, the other BES has to be charged, it can be recharged through the grid at same point of time.

3.2.5 Voltage Dependent Charging Strategies

Voltage dependent charging strategies will help to minimize the impacts due to high EV penetration in distribution system. Various controls used for voltage dependent charging strategies are discussed in [26]. If an EV is connected to a low voltage feeder, the EV will be "penalized" with less reference current resulting in more charging time and efficiency.

3.3 Case Study – System Impacts Resulting from the Presence of EVs

The negative steady state impacts that might emerge from the implementation of uncontrolled charging strategies as well as the benefits arising from controlled EV charging are analysed in [1].

3.3.1 Changes in Load Profile and EV Energy Requirements [1]

For each charging strategy as well as to the changes in the weekly load diagrams, the maximum percentages of EVs that can be safely integrated in the MV network are verified.

The maximum allowable EV integration percentages in the Urban Network are depicted in Figure 3.7. The percentages are relative to the total number of conventional vehicles covered by this network, which was, in this case, 21,135 vehicles. The number of EVs that can be safely integrated in this network for the dumb charging, multiple tariff and smart charging are 5,072, 7,186 and 11,836 respectively. According to the study, the line/Cable overloading is the factor that limits the EV integration in all the charging approaches that are analysed. In the particular cases of the dumb charging and multiple tariff, the overloaded branches are located in the same feeder where the fast charging station is assumed to be installed. Hence, the large amount of power absorbed by the fast charging station is probably the main factor that contributes for the overloading of branches.

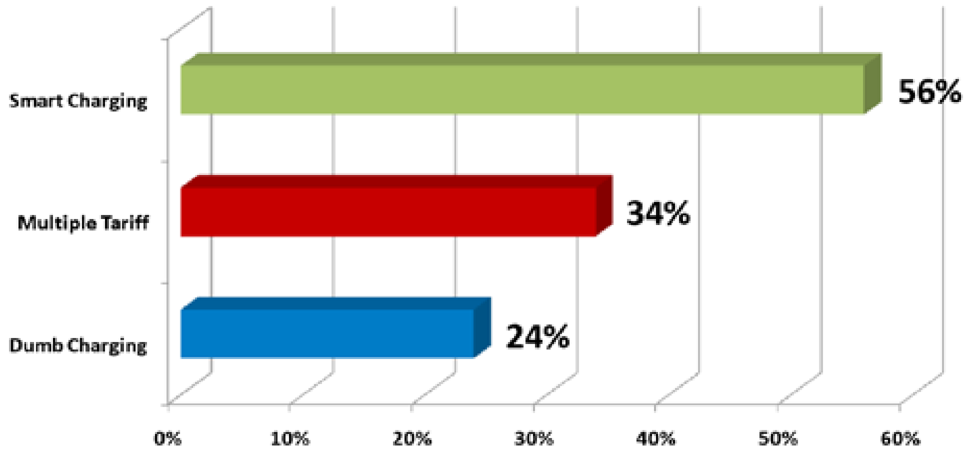


Figure 3.7: Maximum EV integration percentage in the urban network [1]

In the scenario without EV, this network has a peak load of 128.5 MW, which is incremented to 135.6 MW using the dumb charging, 133.9 MW using the multiple tariff and 132.1 MW using the smart charging respectively. Among all, the smart charging can be considered an outstanding achievement, since the peak load only increases by 3.6 MW with an EV integration of 57% for 12,047 EVs.

It is interesting to notice from Figure 3.8, that the EV charging provokes changes in the duration at which the networks' peak load occurs for the dumb charging and the multiple tariffs. In this specific case of network, the peak load changes from 14h to 19h on Thursday. For the smart charging, the hour at which the peak load occurs remains unchanged.

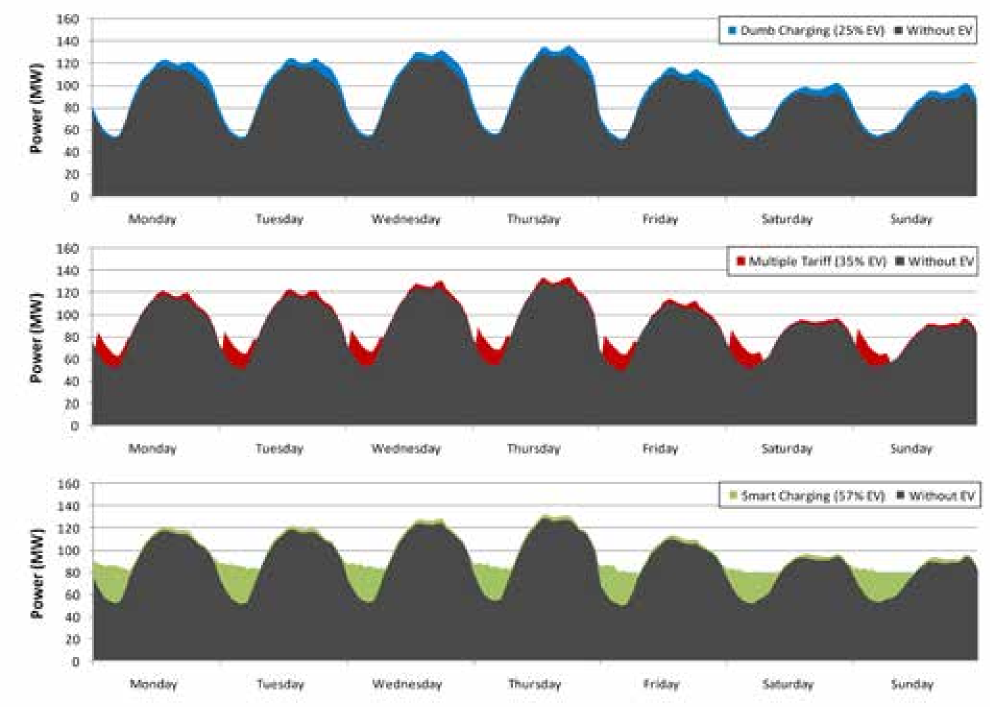


Figure 3.8: Load profiles without and with EV [1]

3.3.2 Voltage Profiles

Figure 3.9 depicts the voltage values obtained in the worst bus of the network, when the maximum allowable EV integration is reached [1]. The values presented are referred to the hour at which the worst voltage conditions in the networks are occurred, which can be different from the hour of the peak load.

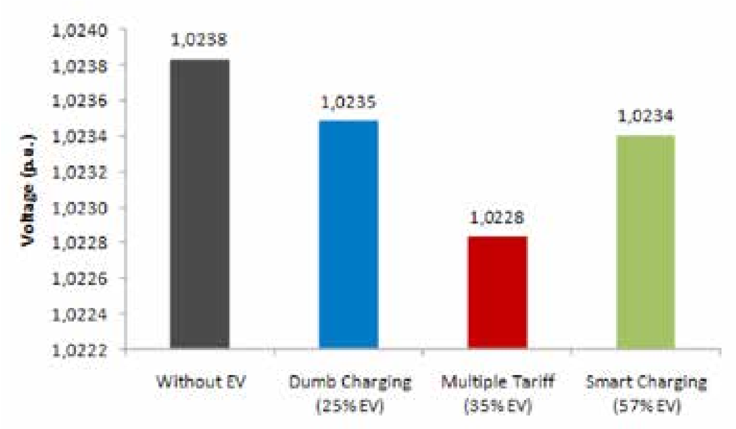


Figure 3.9: Voltage in the worst bus of the Urban Network [1]

As it can be observed, the additional EV demand leads to almost negligible decrease in the voltage values with relation to the initial value (with no EV present in the grids). It is important to recall that, in contrary to LV networks, the X/R ratio of MV networks is high, which makes the impacts of the active power consumed by EV less relevant with respect to the voltage drops. In addition, as this network is from an urban area, it is more prone to congestion problems than under voltage issues.

3.3.3 Line/Cable Congestion levels [1]

Congestion level is the most critical aspect in the network.

In the given scenario, it is assumed that the maximum rating limit allowed is 100%. The three different charging methods are applied on the most congested branch at a specific hour when the worst branch overloading is verified.

Looking at Figure 3.10, the results obtained show that the branches' load levels considerably worsen with the growth of the number of EV present in the grid. In fact, loads of branches are the factors limiting a further EV integration in this case study.

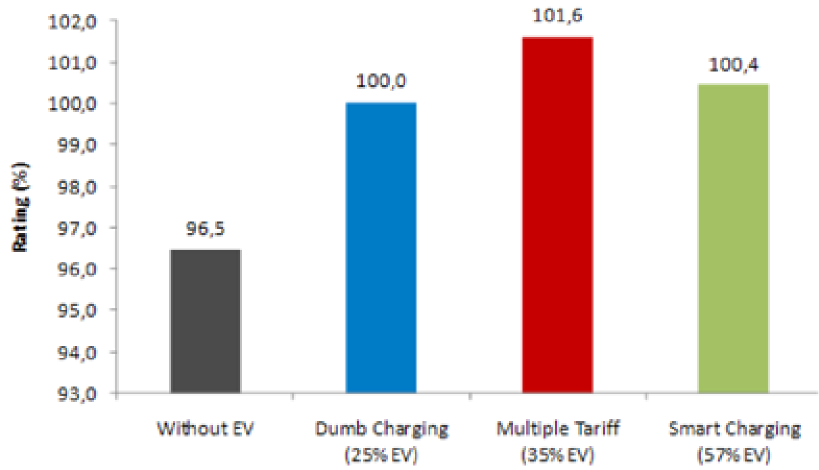


Figure 3.10: Rating in the worst branch of the network [1]

3.3.4 Energy Losses

Looking at [1], it is possible to evaluate the effects of the EV charging on the weekly energy losses of the network. Each bar in the chart presents the absolute value of the losses plotted on the left vertical axis (bars) for various charging methods used and their relative overall energy consumption values (circles) are plotted on the right vertical axis.

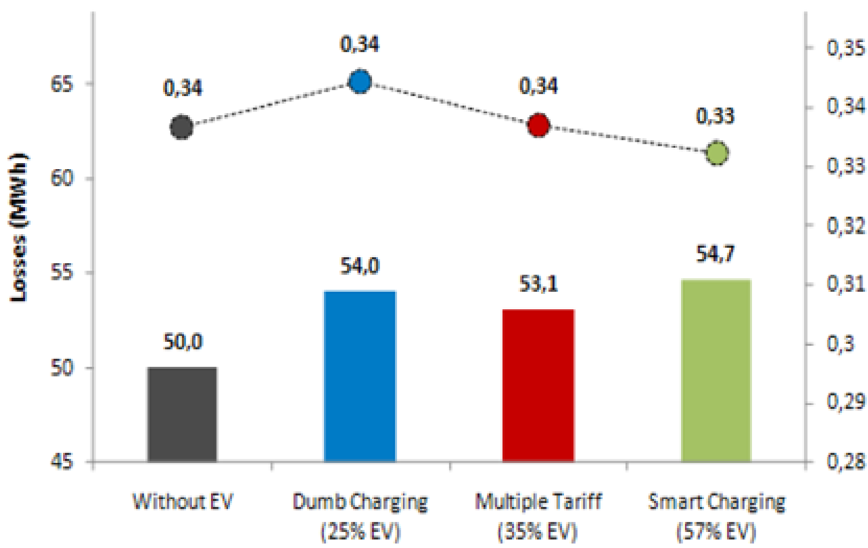


Figure 3.11: Weekly energy losses in the network [1]

Based on the case studies presented in [1], the following summary points are observed.

1. For as on date EV requirements, the analysed system can handle up to a certain level of EV penetration without worrying about the networks' infrastructures
2. The maximum number of EV that can be safely integrated in the networks depends on the charging schemes adopted by the EV owners.
3. From the three strategies analysed (dumb, dual tariff and smart charging), the smart charging strategy yielded better results. It was possible to reach higher EV integration levels without violating the network's technical restrictions.
4. With reference to urban networks, as feeder lengths are short and are subjected to high power demand levels, they are very likely to face branch/transformer overloading problems faster than voltage drop issues.
5. The rural networks usually have long radial lines, which provoke considerable voltage drops. Thus, low voltage problems will probably appear in these grids, especially in the nodes farthest from the feeding points.
6. The extra power demanded by EV also creates several changes in the network's load profiles, which are more prominent as the EV integration level rises.
7. It is also noted that it is impossible to generalise results in a rigorous manner, as the changes induced in the load profiles depend on a large number of factors that are different from network to network.
8. The location of the fast charging stations should be carefully analysed, as they might induce severe voltage violations or branches overloading, due to the large amount of power that they may consume when in full operation.

04

Role of Policies, Regulations and Standards

4.1 Motivation to Adopt Electric Vehicle as a Clean Transport

In light of the growing pollution, the Government of India, over the last few years, has been promoting electric vehicles which are primary among the alternative mobility solutions.

By the year 2030, an estimated 600 million vehicles will be on Indian roads - thrice the current number. With an alarming rise in severe traffic congestion and record-breaking pollution levels at all the major cities including New Delhi and Mumbai, India is in a dire need of new mobility solutions radically. Electric mobility will be a part of that. It is attractive for a number of following reasons:

1. Using the electric vehicles reduces the GHG emission, thereby allowing India to align with their INDC goals.
2. Using the electric Vehicles reduces the Total Cost of Ownership (TCO) as compared to ICE vehicles.
3. Shifting the transport sector's dependency on fossil fuels to the use of electrically powered vehicles will help in reducing India's oil import bill
4. Providing clean, affordable and comfortable transport facility for the Indian population.

However, there are various challenges in adopting electric vehicles. Following are the various barriers in electric mobility sector:

1. High upfront vehicle costs

- In 2018, showroom prices of EVs – whether a car, bus, 3-wheeler or motorcycle - were still 40-100% higher than those of conventional alternatives. The main reasons are the expensive batteries and peripheral electronics that contribute about 50% of total EV cost.

2. Real & perceived range anxiety

- Present EV models tend to have shorter driving ranges than gasoline or diesel vehicles, and charging takes a longer duration than filling up with traditional ICE vehicles. The lack of available and accessible public charging infrastructure adds to the range anxiety concerns.

3. Lack of interoperability and standardization of charging infrastructure

- The interoperability between the vehicles and the chargers made by multiple vendors is crucial for the success of the technology. At present the EV and EVSE market is dominated by three technologies with different connectors and communication protocols which raise concerns of interoperability. CHAdeMO, GB/T and CCS standards define both the connector type as well as the operation/ communication system between charge point and vehicle. The components and systems contained within the charge point are designed specifically for each system. This means that, to change from one system to the other involves significant engineering work in the hardware well beyond mere swapping of plugs. However, manufacturing multi-standard charge points resolves the issue and it is relatively cost effective to include both systems at the time of production.

4. High dependency on government subsidies

Upfront cost of an EV is almost 2-3 times higher when compared to an ICE vehicle of the same segment. A basic EV hatchback model comes in the price range of an ICE mid-range sedan (Rs 10-12 Lakhs). To lower the upfront costs and achieve price parity with ICE, there is a significant dependency on government subsidies.

4.2 Policies

4.2.1 Policies Worldwide

Table 4.1 summarizes many different city-level actions that are promoting the deployment of electric vehicles in major markets around the world [27].

Table 4.1: Overview of city-level policies in electric vehicle capital cities [27]

Category	Program	Leading city	Leading policy	Other examples
Charging infrastructure	City charging strategy	Beijing	Target of 435,000 charge points by 2020, coordination with private partners and State Grid	New York, Oslo, Shenzhen, Shanghai, Tianjin, Guangzhou, Zhengzhou, Qingdao, Chongqing, Wuhan, Hangzhou, Changsha, London, Seattle, Tokyo
	On-demand public charging	Amsterdam	Demand-based allocation of curb side charging fulfilled by utility	
	Charging infrastructure incentives	Tokyo	Large incentives for charging stations at public and multi-unit dwellings	Oslo, Paris, Beijing, Shanghai, Shenzhen, Guangzhou, Tianjin, Hangzhou, Zhengzhou, Qingdao, Wuhan, Chongqing, Changsha
	Building and parking requirements	Beijing	100% of new residential parking spots and 20% of new commercial parking spots must have chargers	Qingdao, London, Shanghai, Tianjin, Chongqing, Guangzhou, Los Angeles, San Francisco, San Jose, Shenzhen, Zhengzhou, Oslo
	Utility partnerships	Guangzhou	Utility construction of smart charging stations	Amsterdam, Los Angeles, New York, Beijing, Shanghai, Shenzhen, Tianjin, Hangzhou

Category	Program	Leading city	Leading policy	Other examples
Fleets and mobility	Taxis	Shenzhen	All new taxis must be electric as of 2017	Amsterdam, London, Oslo, Beijing, Tianjin, Guangzhou
	Electric ride-hailing	London	Only electric ride-hailing by 2025; Uber providing incentives	San Francisco, San Diego, Seattle, Shenzhen
	Electric autonomous testing	San Francisco	Electric autonomous vehicle testing by two leading companies	Beijing, Shanghai , Chongqing, Tokyo
	City fleet	Stockholm	Complete conversion of city car fleet	New York, Seattle, Beijing, Shenzhen, Zhengzhou , Shanghai, Tianjin, Oslo
	Buses	Shenzhen	Complete transition of 16,500 buses	Guangzhou, Tianjin, Changsha, Zhengzhou, Amsterdam
	Car-sharing fleet	Shanghai	Thousands of vehicles in multiple popular all-electric car-sharing fleets	Chongqing, Shenzhen, Beijing, Hangzhou, Guangzhou, Zhengzhou, Oslo, Amsterdam, Los Angeles
Supporting actions	Purchase incentives	Zhengzhou	Offering large upfront subsidies to electric vehicles (as much as 26,400 Yuan in 2017)	Beijing, Shanghai, Shenzhen, Guangzhou, Hangzhou, Tokyo
	Preferential registration	Shanghai	Electric vehicle drivers receive free license plate, avoiding auction system for conventional vehicles	Beijing, Tianjin, Shenzhen, Guangzhou, Hangzhou
	Parking benefits	San Jose	Free parking on street and at municipal garages	Amsterdam, Bergen, Paris, Shenzhen, Tianjin, Oslo
	Toll exemptions	Oslo	Exemption from toll road, bridge, and tunnel charges	Bergen, New York, San Francisco, Chongqing, Wuhan
	Lane access	Bergen	Access to bus lanes	Los Angeles, Oslo, San Francisco, San Jose, San Diego
	Consumer awareness programs	Shanghai	EV demonstration zone with test drives, exhibits, and engagement with manufacturers and utilities emission zones	Amsterdam, Beijing, Los Angeles
	Planned zero-emission zones	London	Zero-emission town centers by 2020 and city center by 2025	London

Some more developments taken at Central level in EV progressive countries are listed in Table 4.2.

Table 4.2: Policy lever and Incentives in EV progressive countries

Countries	Policy lever and Incentives
China	• The Central Government supports municipalities deploying public charging infrastructure by subsidizing the construction of charging stations. • The EVSE are mostly owned by the Govt. • The policy focus is on BEV sales. • Manufacturing subsidies: Billions of dollars have been given in direct subsidies to EV manufacturers. For example, Shenzhen-based manufacturer BYD received USD 435 million in subsidies between 2010 and 2015. The central government allocated over USD 15 billion to support the development of energy-efficient vehicles and electric vehicle infrastructure. • Reduced taxes: EVs were exempted from the standard consumption tax that consumers pay on new automobiles, in as early as 2008. • Customer subsidies: The Chinese government began a consumer subsidy program in 2010 providing approximately USD 8,700 per car. Local governments also created their own subsidy programs that provided additional discounts for NEV purchases through cash subsidies, free parking or free license plates. Both local and central subsidies together accounted for about 20 to 40 % of the cost of the vehicle (to be phased out by 2021). • 50% of government vehicle procurement to be EVs
USA	• A grant of $15 million is approved to expedite public charging infra through American Recovery and Reinvestment Act • Utilities and private parties are actively involved in setting up EV charging infrastructure • The policy focus is on both BEV and PHEV sales • Some common tariff structures for charging are monthly memberships, flat kWh rate, hourly + access fee • Tax credits of USD 2,500 to 7,500 for first 2 lakh units sold per manufacturer • Purchase rebate and tax exemptions by some states
Japan	• National programs have budget provision up to $1 Billion • Program provides grants to local Govt. and highway operators • Subsidy support offered by METI for smooth transition of oil companies to EVs • EVSEs are mostly owned by OEMs • The policy focus is on both BEV and PHEV sales • Some common tariff structure for charging are monthly membership fee, access fee + hourly rate • By 2016, there were more Public charging stations (40,000) compared to filling stations (35,000)

Countries	Policy lever and Incentives
Netherlands	• Green deal (curbside chargers on request) is a national level program with an estimated budget of €33 million • The contracts are tendered to businesses on a case to case basis • Promote PPP model which is accompanied by tax incentive for business investing in EVSE deployments • The primary focus is on PHEV sales • Policy focuses 'differentiated CO2 based taxation scheme • The tax rate on cars with COs emission (ex: PHEV) is EUR 6/gCO2/km. This tax will continue to increase till 2020. • Zero emissions car (BEV) are exempted from car registration tax
Norway	• Enova Grant scheme was launched in 2009 to promote public charger deployments across country with an estimated budget of €11.9 million • Quarterly proposals are invited for targeted projects. For Fast Chargers, bidding based installation across Highways with subsidy cap of €30,000 per charging station. • Slow Charger- No subsidy support i.e. price is market driven. • Leading private operators are Fortum, Green contact and others • The policy focus is on both BEV and PHEV sales • Free public EV charging provided by cities like Oslo • BEVs are exempted from acquisition and VAT • In 2016, higher purchase rebates and tax waivers were introduced for PHEVs compared to 2015 • Waiver on road tolls; free parking discontinued from 2016 onwards
Germany	• Subsidy for 10,000 Level 2 and 5,000 DC chargers. The program budget is of €300 million • 60% subsidy support to all eligible businesses • The policy focus in on both BEV and PHEV sales

As per a China government announcement, the drop in direct subsidies will be replaced by a dual-credit scheme to be launched in 2019. The new scheme will require individual car makers to produce a minimum number of EVs. Those failing to meet the minimum production targets will have to buy credits from competitors with surplus credits. Vehicles that meet their range targets will also earn credits. China is also planning to ban the sale of petrol and diesel cars, in line with some of the European nations like UK and France. However, it has not yet decided on a schedule. The Chinese policies stand as a good learning to countries like India which have been slow on the road to EVs so far.

4.2.2 Policies in India

The summary of various policies in India are presented in Table 4.3.

A variety of reasons has led to the following trend: from infrastructure, policies to early product failures have contributed to this trend. Significant among them are:

- Charging facilities are practically non-existent, some are on pilot phase
- Government support is minimum till date, with rolled back subsidies and delays in the EV policy implementation
- Local manufacturers of components are few and there is a high dependency on Chinese imports.

Table 4.3: Summary of policies in India

EV National Programs	Description
NEMMP 2020	• Year of Launch: 2013 • It is estimated that investment up to Rs 14,000 crore would be required in creating infrastructure and promoting the use of environment-friendly electric vehicles • The policy estimates a sale of 6-7 million EVs by 2020 and a resultant fossil fuel saving of 2.2-2.25 Million Tones
FAME I	• Launch Date: 2015 for 3 years valid till March 31, 2019 • Program Budget: Rs. 795 Cr • Depending on EV model features and technology the following incentives are applicable: o Battery operated scooters and motorcycles- Rs 1,800 to Rs 29,000 o Three-wheeler- Rs 3,300 to Rs 61,000 o Four-wheelers- Rs 13,000 to Rs 1.38 lakhs o Light Commercial Vehicles- Rs 17,000 to Rs 1.87 lakhs o Buses- Rs 33 lakhs to Rs 66 lakhs. • The government has sanctioned a total of 390 buses, 370 taxis and 720 three wheelers as of today. o 390 Buses- The nine big cities (Delhi, Ahmedabad, Bengaluru, Jaipur, Mumbai, Lucknow, Hyderabad, Indore and Kolkata) will be given subsidy for 40 buses each, while Jammu and Guwahati will get subsidy for 15 buses each. o 370 Taxis: Kolkata will get subsidy for 200 e-taxis, followed by Bengaluru for 100 e-taxis, Indore for 50 e-taxis and Ahmedabad for 20 e-taxis o 720 3W: Bengaluru will get subsidy for 500 three-wheelers, followed by Indore for 200 three-wheelers and Ahmedabad for 20 three-wheelers.
FAME II	• The policy is in draft stage, but following announcement is likely to be made, • Program Budget- Rs. 5,500 crores • Subsidy will be given to all categories of electric vehicles. Hybrid vehicles may not be entitled to sops anymore. • Charging Infrastructure subsidy - Rs. 1,000 crore

States are also coming up with their own policies to attract investments. The governments of Maharashtra, Karnataka, Telangana, Uttar Pradesh, Kerala and Delhi have already come out with policies for promoting e-mobility. The section below shows the key highlights for each state policy:

4.2.2.1 Maharashtra

Key highlights of the Maharashtra EV policy (Feb 2018) are the following [28]:

- To support manufacturing of around five lakh battery-powered vehicles in five years. The scheme would help generate one lakh jobs. The first leg will cover six cities: Mumbai, Thane, Pune, Nashik, Aurangabad and Nagpur.
- EV Charging Infra Structure: The Policy envisages four types of charging facilities:
  - Domestic User Facility (Individual User)
  - Public Charging Facility (Govt. facilities, bus depot, railway stations, fuel stations etc.)
  - Common Charging facilities (malls, residential buildings, educational institutes etc.)
  - Commercial Charging facilities (on-road sites, fuel stations etc.)

Incentive and Assistance for EV Charging

- Petrol pumps will be allowed to setup charging stations freely, provided the charging station areas qualify fire & safety standard norms of relevant authorities under relevant acts/rules.
- Commercial public EV charging stations for 2 wheelers, 3 wheelers, cars and buses will be eligible for 25% capital subsidy on equipment/machinery (limited up to Rs. 10 lacs per station) for first 250 commercial public EV charging stations.
- As per the requirement, the facility of Robotic Battery Swapping Arm will be created at public bus stations

Incentives and Provisions for EV Buyer

- 15% subsidy on base price for private transport and individual buyer for Electrical Vehicles registered in the State will be paid to buyer per vehicle. The maximum subsidy limit for each category of vehicle are the following:
  - 2W: INR 5,000/unit (first 70,000 registered in state)
  - 3W: INR 12,000/unit (first 30,000 registered in state)
  - 4W: INR 1,00,000/unit (first 10,000 registered in state)
- 10% subsidy on base price for passenger buses registered in the State to private/public bus transport will be paid to the buyer. The maximum subsidy limit for bus is shown below:
  - Buses: INR 20,00,000 (first 1,000 registered in state)
- Exemption from road tax and registration fees for Electric Vehicles

4.2.2.2 Delhi

Delhi EV Policy, Nov 2018, aims to make every fourth registered vehicle in the capital will be EV by 2023.

Policy Target:

- To bring about a significant improvement in Delhi's air quality by bringing down emissions caused by transport sector. This policy will seek to drive rapid adoption of Battery Electric Vehicles (BEVs) in a manner where they contribute to 25% of all new vehicle registrations by 2023.

- This policy will also seek to put measures in place to support the creation of jobs in driving, selling, financing, servicing and charging of EVs.

The following observations are made from Delhi EV policy [29]:

- 5 years focus with 25% EV new sales target (across all vehicle segments)
- Specificity on 'Advance Batteries' and additional incentivisation of swappable battery system in 2W and 3Ws
- Purchase subsidies over and above Central FAME scheme
- Introducing ICE vehicle scrap incentives
- Allowing corporate EV fleet ownership and clarity (including for 2Ws, 3Ws)
- Promoting retrofit of existing CNG 3Ws to EVs
- Removing limits on e-3Ws permits
- Special provision to ease financing of EVs (to both individuals and enterprises). Both down payment subsidy and interest reduction will go long way in developing good financial instruments for EVs.
- Bringing clarity on permits, transfers and EVs ownership is very useful
- Special up to 20% cash backs for EV fleet rides in 3Ws and 4Ws
- 50% state buses fleet to become EVs by 2023
- Extending purchase incentives to 3W goods vehicle and soft incentives to park during non-park times
- Recognising that home and office charging shall form the highest percentage of charging and supporting them with up to 100% capital subsidy for both residential and non-residential. Clarity on Bharat Charger AC-001 is an important step.
- Extending EV category electricity single-point tariff at Rs. 5.5/kWh to home, office and another type of charging location (in addition to public charging). Providing clarity that for the next 5 years, this rate can only reduce but not increase.
- Dividing Delhi city into 11 travel districts and inviting bids for public charging station setup for each of these travel districts. Defining at least one public charging station for every 3 km^2 grid can help with improving perception. Bidding to be based on the lowest capital subsidy and density of charging points. The operators can decide their pricing strategy and shall be given minimum 10 years of ownership. It is good to have clarity on Bharat Chargers AC-001 and DC-001 specs and any of its future upgradation.

  o Battery swapping operators shall be recognised for public charging and only 3 operators that shall be invited for the city which is defined as the city limit. Bidding basis of Rs. 5.5/kWh charge to end-user would need to be looked at. Operator should be allowed to charge at open market price.

- For swappable battery operator, it confirms a refund of 100% SGST, which is a good direction and a lever to reduce cost for the operator
- It allows an Energy Operator to pool its charging load across sites and opt for Open Access base on cumulative load > 1MW
- A Plan that helps the charging operator to share data with an open Govt. set dataset, which intern be shared with app aggregators is a well-planned thought.
- Suggesting clear mechanism for EV batteries reuse, recycling, appointing aggregators and nodal agency is a good direction. Having public information on reuse (secondary market) and

recycle will bring lot of confidence to the financiers.

- It is good that Delhi Govt. is not looking to fund these incentives from its budget, but through pooled State EV fund, financed by penalising ICEs by pollution cess, parking charges increase, road tax, 2.5% ride hailing congestion fee and Environment Compensation Charges.
- Focus on making Delhi the hub for training EV vocational courses and (re)skilling professionals
- Laying clear Committee structure to overlook this policy implementation and empowering them with rights to change policies to meet the goal of 25% new vehicles sales by 2023.

4.2.2.3 Uttar Pradesh

Key highlights of the UP EV policy are the following [30]:

Buyer's Incentives

- 100% exemption of road tax on Transportation EVs purchased and Vehicle registration fees of EVs manufactured within Uttar Pradesh
- 100% Interest free loans to State Government employees

Incentives to Service Providers

- Service units setting up charging stations with capital investment of more than Rs. 25 lacs but less than Rs. 5 crore, will be provided Capital Interest Subsidy @5% per annum for 5 years in the form of reimbursement on loan for procurement of plant & machinery and setting up charging infrastructure (excluding land cost) subject to a maximum ceiling of Rs. 10 lacs per annum per unit and for those service unit with less than 25 lacs investment with be given same Capital Interest subsidy rate, but subject to maximum ceiling of Rs 2 lacs per annum per unit
- All service units will be eligible for 100% exemption from paying electricity duty for 10 years

Other Provisions

- Public Transportation – In order to promote EV vehicles in Public Transportation, 1,000 EV buses will be introduced by the State by 2030, in phases. 25% in phase I by 2020, remaining 35% in phase II by 2022 and rest 40% in phase III by 2030.
- Private transportation – Auto rickshaws, Cabs, School buses/vans, etc will be targeted to achieve 100% electric mobility by 2030 in five cities – GB Nagar, Ghaziabad, Lucknow, Kanpur, Varanasi.
- State Govt. will promote EV battery and charging equipment manufacturing in Uttar Pradesh

4.2.2.4 Telangana

Key highlights of draft Telangana EV policy (Sep 2017) are the following [31]:

- Policy Target: Attract investments worth $3 Billion and generate employment for 50,000 persons by 2022 through EV manufacturing and charging infrastructure development in Telangana State
- The EV policy is targeted to achieve 100% migration of EV by 2030 in Telangana
- Incentive: For personal mobility, registration charges to be exempted till 2025.
- Power Tariff: Telangana power utilities have forwarded a proposal to levy Rs. 6.10/kWh from the upcoming electric vehicle (EV) charging stations.

- Corporate Offices with annual turnover of INR 100 Cr+ operating within GHMC limits to compulsorily migrate 25% of their employee commuting fleet to EV by 2022 and 100% by 2030.
- Charging points will be setup at Govt. office parking lots.
- Establish an adequate network of charging/swapping infrastructure
- Encourage cab operators/aggregators to switch to full EV fleet in phased manner
- Govt. to setup first 100 fast charging stations in GHMC and other cities in a phased manner
- A viable business model will be developed for private players to set up ARAI (Automotive Research Association of India) compliant EV charging stations/infrastructure at public places such as airports, railway/metro stations, parking lots, bus depots, markets and malls.
- A separate category of Power tariff will be created for EV Charging, both public and private. Duty exemption on power tariff will be extended to public charging stations for duration of 5 years.
- Amendment to building and construction laws will be made to ensure that all new constructions shall comply with the law to integrate charging infrastructure at the planning stage onwards.
- Supply of Renewable energy will be ensured on preferential basis at special tariffs for EV charging stations with zero connection cost and wheeling charges
- Charging/swapping station will be installed at every 50 km within the state boundaries on highway to cities like Bengaluru, Mumbai and Chennai.

4.2.2.5 Karnataka

Key highlights of the Karnataka Electric Vehicle and Energy Storage Policy (Sep 2017) are the following [32]:

- Policy aims to attract investments worth Rs 31,000 crores in electric vehicle manufacturing and charging infrastructure
- State Transport BMTC, KSRTC, NWKSRTC and NEKRTC will introduce 1,000 EV buses during time-period of 5 years
- Incentives for Electric Vehicle
  - 2W – INR 7,500 – 22,000/unit
  - 4W – INR 13,000 – 6,10,000/unit
  - Buses – INR 8,500,000 – 10,000,000/unit
- Battery Swapping Station Subsidy: 25% on equipment and machinery
  - 2W/3W- First 100 stations (max. Rs. 3 lakhs)
  - 4W- First 50 stations (max. Rs. 5 lakhs)
  - Buses- First 50 stations (max. Rs. 10 Lakhs)
- Fast charging station for all vehicle types - First 100 stations (maximum of Rs. 10 Lakhs)
- Building Code Amendments - The amendments will be made to building bye-laws for providing charging infrastructure for EVs in all high-rise buildings/technology park/apartments in the state.
- BESCOM has proposed following tariff for EV Charging Stations:
  - Rs 4.85 per unit of power between 6am–10pm

- o Rs 3.85 per unit of power between 10pm–6am
- o Rs 5 per unit for fast charging in the day and Rs 4.40 at night

4.2.2.6 Kerala

Key highlights of draft EV policy for Kerala are the following [33]:

- Government has assigned a task force to develop e-mobility road-map, with a pilot fleet of 2,00,000 two-wheelers, 50,000 three-wheelers, 1,000 goods carriers, 3,000 buses and 100 ferry boats, ready and in operation, by 2020.
- Auto rickshaws are the front-runners of the shift to EVs as the state aims 100% electrification of vehicles by 2030.
- The newly registered EVs will get a three-year exemption on road tax. Manufacturers will be entitled to electricity at concessional tariff, tax breaks, priority in allotment of land and investment allowance under Centre's 'Make in India' policy.
- The current plan is to adopt swappable battery model as the prime mode of battery recharging. 20 charging stations are to be set up in three pilot districts and 150 swapping stations of 2W/3W/4W capacity.
- Under early adoption support scheme, an incentive of Rs 30,000 or 25 percent of the EV (whichever is lower) for three wheelers will be provided for the initial period of one year.
- Subsidised electricity with tariff between Rs.5-5.5 per unit for EV charging stations.

So policy, by its very definition has different connotations and policy elements across jurisdictions. The section below summarizes broadly a few examples of Policy initiatives in the Electric Vehicles Industry value chain area globally

- Electric vehicle production: China, Europe, Japan, South Korea and the United States account for nearly all global electric vehicle production. China's electric vehicle production is the highest with 50% of global production in 2017, followed by Europe with 21%, the United States with 17%, Japan with 8% and South Korea with 3%. Of the top 20 electric vehicle manufacturers, nine have headquarters in China, four in Europe, three in the United States, three in Japan and one in South Korea.
- Electric vehicle battery production: From 2011 to 2015, Japan, by a wide margin was the world's largest producer of battery packs for electric vehicles. By 2016, China's battery cell production for electric vehicles overtook that of South Korea and Japan. In 2017, China's battery cell production for light-duty electric vehicles was 11 times that of the United States and 22 times that of Europe. Based on industry announcements of battery cell production through 2022, China accounts for more than half, compared to 12%–17% each for Europe, South Korea, and the United States.
- Electric vehicle promotion policy: Several policies are helping to overcome barriers in adopting electric vehicle of limited model offerings, cost and convenience, especially across China, Europe and the United States. More than 80% of the world's new automobiles are subject to standards that provide a foundation for industry investments in vehicle technology. In addition, the leading market also has direct regulations for electric vehicles, consumer incentives and charging infrastructure investments in place.

- Electric vehicle industrial policy: China has comprehensively promoted domestic and foreign investment in batteries and electric vehicles with its central planning and reinforcing local policy. Setting clear volume targets and providing financial incentives ultimately has vested governments and companies in developing an electric vehicle market and a manufacturing base. Policies in the United States and Europe to spur similar electric vehicle and battery investments have been comparatively limited.

4.3 Regulations

Ministry of Power (MoP) clarified that EV charging will be considered a service and not a resale of electricity. The charging of battery involves utilization of electrical energy which gets stored in the battery. Thus, the charging of battery of an EV involves a service by the charging station and earning revenue from the EV owner. The electricity is consumed within the premises owned by the charging station and hence is not a sale of electricity [34].

As per the recent guidelines given by Ministry of Power on 14th Dec 2018 on "Charging infrastructure for Electric Vehicles – Guidelines and Standards," [35], the following key points are presented below.

1. Private charging at residences/offices shall be permitted. DISCOMs may facilitate the same.
2. Setting up of Public Charging Stations (PCS) shall be a de-licenced activity and any individual/entity is free to set up public charging stations and connectivity will be provided by DISCOM.
3. Any charging station/chain of charging stations may also obtain electricity from any generation company through open access.
4. Public charging stations shall have one or more electric kiosk/boards with installation of all the charger models as shown in Table 4.4.

Table 4.4: Various charging models

Charger Type	Charger Connectors*	Rated Voltage (V)	No. of Charging points/ No. of Connector guns (CG)
Fast	CCS (min 50 kW)	200- 1000	1/1 CG
	CHAdeMO (min 50 kW)	200-1000	1/1 CG
	Type-2 AC (min 22 kW)	380-480	1/1 CG
Slow/Moderate	Bharat DC-001 (15 kW)	72-200	1/1 CG
	Bharat AC-00 1 (10 k W)	230	3/3 CG of 3.3 kW each
*In addition, any other fast/slow/moderate charger as per approved BIS standards whenever notified.			

5. Tie up with at least one online Network Service Providers (NSPs) to enable advance remote/ online booking of charging slots, location and type of charger etc.
6. Sharing of charging station data with DISCOM with appropriate protocols.
7. Electric Vehicle Supply Equipment (EVSE) shall be type tested by an appropriate reputed authority.
8. Public charging station can also have the option to add standalone battery swapping facilities in addition to the above mandatory facilities.
9. Captive charging infrastructure for 100% internal use for a company's own/leased fleet for its own use will not be required to install all type of chargers and to have NSP tie ups.

10. The tariff shall not be more than the average cost of supply plus 15% and will be determined by appropriate commission.

11. Priority for rollout of EV charging infrastructure:

a. Phase 1 (1-3 years)

   All mega cities with population of 40 Lakhs plus as per census 2011, all existing expressways connected to these mega cities and important Highways connected with these mega cities

b. Phase 2 (3-5 years)

   Big cities like State capitals, UT headquarters and important Highways connected with these cities

4.3.1 Grid Connectivity Regulations in India

As per report by Forum of Regulators (FOR) [36], since EV charging is a load on the distribution system no modification in IEGC (which basically covers Regulations for ISGS, ISTS and Load Dispatch Stations etc.) is envisaged. As per FOR analysis, no specific modification in the IEGC are needed for EV charging.

The following recommendations were made by the CEA, regarding Standards for charging station:

- Applicant shall provide a reliable protection system to detect various faults/abnormal conditions and provide an appropriate means to isolate the faulty equipment or system automatically. The applicant shall also ensure that fault of his equipment or system does not affect the grid adversely.
- The licensee shall carry out adequacy and stability study of the network before permitting connection with its electricity system.

Power Quality Standards

- The limits of injection of current harmonics at Point of Common Coupling (PCC) by the user, method of harmonic measurement and other matters shall be in accordance with the IEEE 519-2014 standards, as amended from time to time.
- Prosumer shall not inject direct current greater than 0.5% of rated output at interconnection point.
- The applicant seeking connectivity at 11 kV or above shall install Power Quality meters and share data as and when required by the licensee. Users connected at 11 kV or above shall comply with this provision within 12 months of notification of these regulations.
- In addition to harmonics, the limits and measurement of other power quality parameters like voltage sag, swell, flicker, disruptions, etc. shall be as per relevant BIS standards or as per IEC/IEEE standards if BIS standards are not available.

Considerations for V2G, Integration of Solar PV and Storage

- Globally, low level EVSE doesn't require communication. However, in India it is essential for low level EVSEs or slow chargers to also have provision for communications. EV being charged with a slow charger can better support in grid stability through V2G application as it would be parked for longer duration and connected to grid. As time of connection to grid will be longer as compared to EV connected through fast chargers, higher reliability could be achieved. Users of fast chargers would be connected for very short duration and could support only minimally.

- The peak hours of solar and wind might match with EV charging patterns. Power generation with help of GRPV to cater to demand of EV charging could help address technical losses and stability concerns of distribution utilities.
- With applications such as vehicle to home or vehicle to grid that utilizes batteries of EVs as dynamic storage media could result in multiple points of injection of power in distribution network managing that could aid in enhancing the resilience of the grid, if the system is designed well. (However, power flow studies and load flow analysis need to be conducted to understand if the nodes of network where these assets could be deployed for viable business operations are resilient enough to absorb the impact of sudden power injection and drawals. There is a need to study the impact of VRE, storage and EV charging on distribution networks in a holistic manner.)

4.3.1.1 Building Codes

Town and Country Planning Organisation under the ministry of housing and urban affairs has prepared a draft enabling guidelines for electric vehicle charging infrastructure, based on which governments shall amend their building by-laws and master plan regulations. The proposals include offering round the-clock charging infrastructure facility to all electric vehicles in residential buildings, setting up charging bays at 20% capacity of all vehicles, on-spot metering and payment services in both commercial and residential buildings [55].

4.3.2 Grid Connectivity Regulations in European Countries

In Europe, the Distribution system should not violate the grid parameters limits even with high EV and roof top solar penetrations.

4.3.2.1 Great Britain

As per the Distribution Code of Licensed Distribution Network Operators (DNO's) of Great Britain [37], the following are the standards observed:

Distribution Planning and Connection Code (DPC)

Standard of Supply

Frequency and Voltage:

The Frequency of the Distribution Network Operator (DNO)'s System shall be nominally 50Hz and shall normally be controlled within the limits of 49.5 - 50.5 Hz in accordance with principles outlined in, The Electricity Safety, Quality and Continuity Regulations (ESQCR) [38].

In exceptional circumstances, system frequency could rise to values of the order of 52 Hz or fall to values of the order of 47 Hz. Sustained operation with the range 47 - 52 Hz is not taken into account in the design of plant and apparatus.

Any extension or connection to the DNO's system shall be designed in such a way that it does not adversely affect the voltage control employed on the DNO's system.

As per ESQCR the permitted voltage variations are the following-

- A variation not exceeding 1 per cent above or below the declared frequency
- In the case of a low voltage supply, a variation not exceeding 10 per cent above or 6 per cent below the declared voltage at the declared frequency

- In the case of a high voltage supply operating at a voltage below 132,000 volts, a variation not exceeding 6 per cent above or below the declared voltage at the declared frequency
- In the case of a high voltage supply operating at a voltage of 132,000 volts or above, a variation not exceeding 10 per cent above or below the declared voltage at the declared frequency

Voltage Disturbances and Harmonic Distortion:

As per BS EN 50160:2010 'Voltage Characteristics of Electricity Supplied by Public Distribution Systems' [39], the allowed voltage disturbances and harmonic distortions for MV and LV network of Distribution system are presented Table 4.5 and Table 4.6.

Table 4.5: Comparison of supply voltage requirements according to EN 50160 and the EMC standards EN 61000 [39]

No	Parameter	Supply voltage characteristics according to EN 50160	Low voltage characteristics according to EMC standard EN 61000	
			EN 61000-2-2	Other parts
1	Power frequency	LV, MV: mean value of fundamental measured over 10 s ±1% (49.5 - 50.5 Hz) for 99.5% of week -6%/+4% (47- 52 Hz) for 100% of week	2%	
2	Voltage magnitude variations	LV, MV: ±10% for 95% of week, mean 10 minutes rms values		±10% applied for 15 minutes
3	Rapid voltage changes	LV: 5% normal 10% infrequently Plt ≤ 1 for 95% of week MV: 4% normal 6% infrequently Plt ≤ 1 for 95% of week	3% normal 8% infrequently Pst < 1.0 Plt < 0.8	3% normal 4% maximum Pst < 1.0 Plt < 0.65 (EN 61000-3-3) 3% (IEC 61000-2-12)
4	Supply voltage dips	Majority: duration <1s, depth <60%. Locally limited dips caused by load switching on: LV: 10 - 50%, MV: 10 - 15%	urban: 1 - 4 months	up to 30% for 10 ms up to 60% for 100 ms (EN 61000-6-1, 6-2) up to 60% for 1000 ms (EN 61000-6-2)

5	Short interruptions of supply voltage	LV, MV: (up to 3 minutes) few tens - few hundreds/year Duration 70% of them < 1 s		95% reduction for 5 s (EN 61000-6-1, 6-2)
6	Long interruption of supply voltage	LV, MV: (longer than 3 minutes) <10 - 50/year		
7	Temporary, power frequency over voltages	LV: <1.5 kV rms MV: 1.7 Uc (solid or impedance earth) 2.0 Uc (unearthed or resonant earth)		
8	Transient over voltages	LV: generally < 6kV, occasionally higher; rise time: ms - µs. MV: not defined		±2 kV, line-to-earth ±1 kV, line-to-line 1.2/50(8/20) Tr/Th µs (EN 61000-6-1, 6-2)
9	Supply voltage unbalance	LV, MV: up to 2% for 95% of week, mean 10 minutes rms values, up to 3% in some locations	2%	2% (IEC 61000-2-12)
10	Harmonic voltage	LV, MV: see Table 4.6	6%-5th, 5%-7th, 3.5%-11th, 3%-13th, THD <8%	5% 3rd, 6% 5th, 5% 7th, 1.5% 9th, 3.5% 11th, 3% 13th, 0.3% 15th, 2% 17th (EN 61000-3-2)
11	Inter-harmonic voltage	LV, MV: under consideration	0.2%	

Table 4.6: Values of individual harmonic voltages at the supply terminals for orders up to 25, given in per cent of Un [39]

Odd harmonics				Even harmonics	
Not multiples of 3		Multiples of 3			
Order h	Relative voltage (%)	Order h	Relative voltage (%)	Order h	Relative voltage (%)
5	6	3	5	2	2
7	5	9	1.5	4	1
11	3.5	15	0.5	6.….24	0.5
13	3	21	0.5		
17	2				
19	1.5				
23	1.5				
25	1.5				

Voltage Step Changes:

- Typical limits for voltage step changes caused by the connection and disconnection of User's Equipment or Customer's Demand to the DNO's Distribution System, are ±3% for infrequent planned switching events or outages (in accordance with Engineering Recommendation P28).
- For unplanned outages such as faults, it will generally be acceptable to design to a voltage step change of ±10%.

4.3.2.2 Ireland

As per the Distribution Code-ESB Networks-Ireland [40], the following points are observed.

- The Distribution System and any User connections to that system shall be designed to enable normal operating Frequency and voltages supplied to Customers to comply with European Standard EN 50160:1995 Voltage Characteristics of Electricity Supplied by Public Distribution System [39].
- Information Required for Connection
  a. For connections at Low Voltage, it is possible in most cases to assess whether a proposed connection is acceptable and to determine the necessary supply arrangements from analysis of the following data:
     - o Maximum kVA requirements
     - o Type and electrical loading of equipment to be connected, such as number and size of motors, cookers, showers, space and water electrical heating loads and nature of disturbing loads e.g. welding equipment
     - o The date when connection is required

  b. The provisions of the above point also apply to connections at high and medium voltages. Additionally, the following information may be required
     i. All Types of Demand:
     - Maximum active power requirements
     - Maximum and minimum reactive power requirement
     - Type of load and control arrangements (e.g. type of motor start, controlled rectifier or large motor drives)
     - Maximum load on each phase
     - Maximum harmonic currents that may be imposed on the distribution system
     - Details of cyclic load variations or fluctuating loads (as below)

     ii. Disturbing Loads:

     These are loads which have the potential to introduce harmonics, flicker or unbalance to the system. This could adversely affect the supply quality to other customers. Disturbing loads could be non-linear loads, power converters/regulators and loads with a widely fluctuating demand. The type of load information required for motor power loads, welding equipment, harmonic producing or non-linear loads and generating equipment can be obtained from the DSO on request.

In the case of compensating equipment associated with disturbing loads, details and mode of operations are to be provided so as to ensure compliance with harmonic emission limits specified in this regulation.

iii. Fluctuating Loads:

Details of cyclic variation and where applicable the duty cycle, of Active Power (and Reactive Power if appropriate), in particular:

- The rates of change of active power and reactive power, both increasing and decreasing
- The shortest repetitive time interval between fluctuations in active power and reactive power
- The magnitude of the largest step changes in active power and reactive power, both increasing and decreasing

- Connection Arrangements

Based on the information provided by the user for a connection to the distribution system, the DSO shall prepare a statement containing as many of the following elements as are necessary for, or relevant to, the proposed installation:

a. Nominal voltage at which connection will be made

b. Method of connection, extension and / or reinforcement details

c. The normal impedance to source at the point of connection

d. Method of earthing

e. Maximum import capacity

f. Individual Customer limits relating to:

i. Harmonic distortion

ii. Voltage flicker

iii. Unbalance

g. Expected lead time of providing connection (following formal acceptance of terms for supply)

h. Cost of connection

- Voltage Regulation and Control

Extensions or connections to the Distribution System shall be designed such that they do not prevent the necessary control of voltage on the distribution system.

- Voltage Disturbances

Loads and installations shall comply with the following emission limits

a. Voltage Flicker

i. Frequency of occurrence: 0.22 per min – 600 per min

Voltage Level	Pst	Plt
38kV, MV, LV	0.7	0.5

Pst: Short term Flicker severity
– An index of visual severity evaluated over a 10-minute period.

Plt: Long term Flicker severity
– An index of visual severity evaluated over a 2-hour period

ii. Frequency of occurrence: 0.02 per min – 0.22 per min
Magnitude of up to 3% is permitted.

iii. Frequency of occurrence: =< 0.02 per min
Magnitude of up to 5% is permitted.

b. Harmonic Distortion

i. Individual Harmonic Orders:

Percentage of Harmonic Voltage Distortion (RMS voltage as a % of RMS value of the fundamental component)

Harmonic Order	LV	MV	38kV
2	0.7	0.5	0.25
3	0.75	0.5	0.25
4	0.7	0.5	0.25
5	2	1	0.5
6	0.5	0.5	0.3
7	2	1	0.5
8	0.5	0.5	0.3
9	0.5	0.5	0.25
10	0.5	0.75	0.25
11	1.5	1.5	0.75
12	0.5	0.5	0.3
13	1.5	1.5	0.75
14	0.5	0.5	0.5
15	0.5	0.75	0.25
16	0.75	0.75	0.25
17	0.75	0.75	0.5
18	0.5	0.5	0.25
19	1	0.5	0.25

c. Voltage Unbalance

The unbalance caused by the connection of an individual installation shall not exceed 1.3% at the Point of Common Coupling (PCC).

- Power Factor and Phase Balance

> The Customer shall take all reasonable steps to operate the plant and the facility to keep the power factor of the total load at the connection point for imported electricity between 0.90 lagging and unity; for exported electricity between 0.95 lagging and unity. Wind generators must keep power factor between 0.92 and 0.95 lagging. For the purpose of this code, lagging power factor refers to the absorption of reactive power. These are the minimum requirements. In certain instances, specific requirements may apply in order to ensure that the DSO can comply with the requirements of the grid code.

4.4 Standards

Standardisation is a method that ensures products and processes conform to levels of performance, quality and safety which satisfy all stakeholder requirements. The introduction of charging standards in the EV market will be an enabler of mass market uptake of EVs, allowing original equipment manufacturers to reduce costs and accelerate charging infrastructure investment, whilst allowing EV consumers a cheaper, more consistent and safer experience of owning/operating an EV.

There are numerous standards development and regulatory efforts underway worldwide. The following overview highlights a slice of the global interest in this application space [4]:

1. Local jurisdictions may have special permissions in place for EV Service Equipment (EVSE) as well as local utility standards for integration with grid services and both vary greatly by jurisdiction worldwide. For example, in California, assembly Bill 1236 requires cities and counties with a population of more than 200,000 to adopt specific governance processes to accelerate EVSE installation.
2. More broadly, industry bodies and standards development consortiums are advancing the agenda on the integration of electric transportation concerning many aspects of smart cities including public transportation, commercial fleets, workplace charging, autonomous and shared mobility applications. for example, in the IEEE IoT consortium (iot.ieee.org), the Smart cities Working Group (WG) is tackling applications for use in the transportation, energy, social good, public service and many other domains drawing on development effort from IEEE P2413, Standard for an Architectural Framework for the Internet of Things.
3. Transportation electrification efforts and DER growth worldwide are also driving regulatory approval of V2G and are subsequently increasing utility investment in EV and energy-storage integration with grid resources, accelerated markets and program adoption. Reflecting these interests, standards efforts are now underway to advance energy system capability maturity for EV and ESS (Energy Storage System) integration.
4. Specific to vehicle charging safety, Underwriters Laboratories (UL) 2594 and UL 2202, Standard for Electric Vehicle Supply Equipment and Standard for Electric Vehicle Charging System Equipment are used respectively. They cover level 1, 2 and DC fast-charging applications, while UL 9741, Outline of Investigation for Bidirectional Electric Vehicle Charging System Equipment, covers the export of power-to-power systems and the safety of bidirectional EV charging systems and equipment.
5. Vehicle plug standards are also key to effective integration with significant work underway in standards such as the following:

    - International Electrotechnical Commission (IEC) 62196, plugs, socket outlets, vehicle connectors and vehicle inlets-conductive charging of electric vehicles
    - The Society of Automotive Engineers (SAE) international J 2954 standards for wireless

power transfer (up to 11 kW), wireless power transfer for light-duty plug-In/electric vehicles and alignment methodology

- J 1772 standard for plug connections, electric vehicle and plug-In hybrid electric vehicle conductive charge coupler
- Japan EV Association Standard G105 (called CHAdeMO), connectors applicable to quick-charging system at eco-station for EVs
- SAE J 2954, released in December 2017, also has techniques for testing vehicle systems and automating the commercial transaction with a wireless charging station (i.e., without operator involvement)

Various standardization bodies have identified key global standards regarding overall safety for charging station, EVSE safety, AC/ DC charging connector, EV - EVSE communication protocols and V2G as important step for EV uptake. Table 4.7 shows the global EVSE related standards.

Table 4.7: Global EVSE related standards [41]

Category	Name of Standard	Title
Overall Charging Station Related Safety	IEC 61851-1	Electric vehicle conductive charging system — Part 1: General requirements
	IEC 61851-21-1	Electric vehicle conductive charging system - Part 21-1 Electric vehicle on-board charger EMC requirements for conductive connection to AC/DC supply
	IEC 61851-23	Electric vehicle conductive charging system — Part 23: DC electric vehicle charging station
	IEC 61851-24	Electric vehicle conductive charging system - Part 24: Digital communication between a DC EV charging station and an electric vehicle for control of DC charging
	GB/T 18487.1-2015	Electric vehicle conductive charging system. Part 1: General requirements
	GB/T 18487.2-2001	Electric vehicle conductive charging system - Electric vehicles requirements for conductive connection to an AC/DC supply
	GB/T 18487.3-2001	Electric vehicle conductive charging system AC/DC Electric vehicle charging station
	ISO 17409	Electrically propelled road vehicles — Connection to an external electric power supply — Safety requirements
EVSE Safety	IEC 61140	Protection against electric shock–Common aspects for installation and equipment
	IEC 61000-6-2	Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity standard for industrial environments
	IEC 61000-6-3	Electromagnetic compatibility (EMC) - Part 6-3: Generic standards - Emission standard for residential, commercial and light-industrial environments

Category	Name of Standard	Title
AC Charging and Connectors	IEC-62196-2 (normal + high power)	Plugs, socket-outlets, vehicle connectors and vehicle inlets — Conductive charging of electric vehicles — Part 2: Dimensional compatibility and interchangeability requirements for AC pin and contact-tube accessories
	IEC 60309-1	Plugs, socket-outlets and couplers for industrial purposes — Part 1: General requirements
	IEC 60309-2	Plugs, socket-outlets and couplers for industrial purposes — Part 2: Dimensional interchangeability requirements for pin and contact-tube accessories
	SAE J 1772 (Type 1)	SAE Electric Vehicle Conductive Charge Coupler
	GB/T 20234.2-2015 AC	Connection set for conductive charging of electric vehicles - Part 2: AC charging coupler Electric Vehicle Connection Set - AC Charging Coupler
DC Charging and Connectors	IEC-62196-3 (normal + high power)	Dimensional compatibility and interchangeability requirements for DC and AC/DC. pin and contact-tube vehicle couplers
	GB/T 20234.3-2015	Connection Set for Conductive Charging of Electric Vehicles - Part 3: DC Charging Coupler
Vehicle to grid standard	ISO 15118-1	Road vehicles — Vehicle to grid communication interface - Part 1: General information and use-case definition
	ISO 15118-2	Road vehicles — Vehicle to grid communication interface - Part 2: Network and application protocol requirements
	ISO 15118-3	Road vehicles — Vehicle to grid communication interface - Part 3: Physical and data link layer requirements
	ISO 15118-4	Road vehicles — Vehicle to grid communication interface - Part 4: Network and application protocol conformance test
	ISO 15118-5	Road vehicles — Vehicle to grid communication interface - Part 5: Physical layer and data link layer conformance test
	ISO 15118-8	Road vehicles — Vehicle to grid communication interface - Part 8: Physical layer and data link layer requirements for wireless communication
Other Vehicles related safety	ISO 6469-4	Electrically propelled road vehicles -- Safety specifications -- Part 4: Post crash electrical safety
	ISO 26262	Road vehicles – Functional safety

The full spectrum of standards required for an integrated charging system in the U.S. is presented in Figure 4.1.

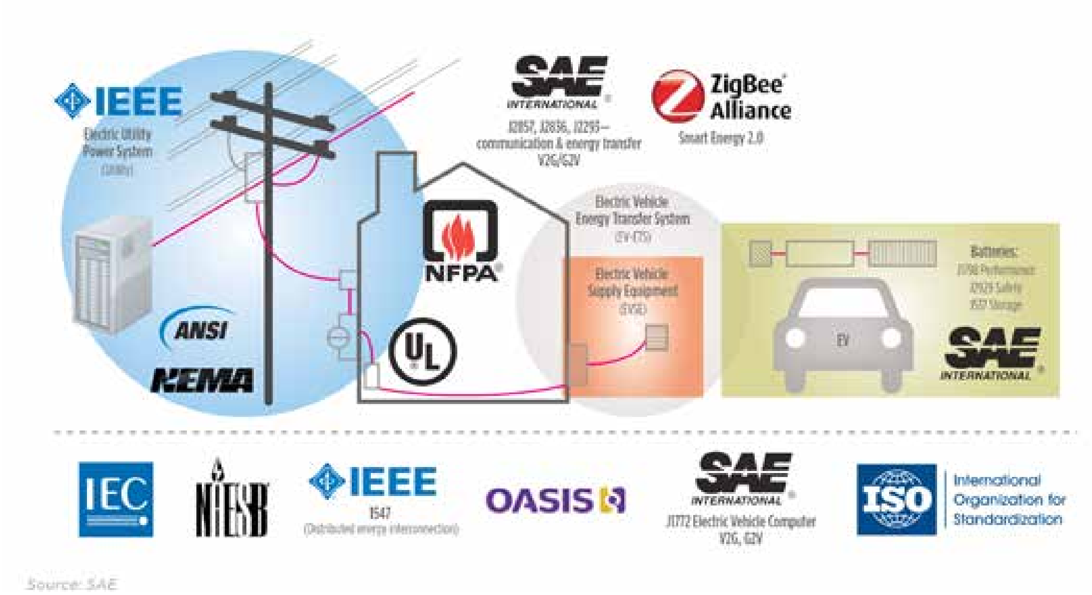


Figure 4.1: The full spectrum of standards required for an integrated charging system in the U.S. [42]

4.4.1 Standards on Electric Vehicle Charging Stations in India

In India, IS 15886 was drafted for standardization of Electric and Hybrid vehicles and their components by Bureau of Indian Standards (BIS). Some standards were drafted by ARAI which includes the following:

- AIS-138 (Electric Vehicle Conductive AC Charging System) for DC charging system for electric vehicles with assistance from existing international standards including IEC 61851-1(General Requirements), IEC 61851- 23 (electric vehicle charging station) and IEC 61851-24 (Digital communication) [43].
- ARAI has also published AIS document including AIS-102 (Part 1 & 2) on CMVR Type Approval for Hybrid Electric Vehicles, AIS-123 on CMVR Type Approval of Hybrid Electric System Intended for Retro-fitment and AIS 131 on type Approval Procedure for Electric and Hybrid Electric Vehicles introduced in market for Pilot / Demonstration Projects intended for government schemes.

In late 2017, the Ministry of Heavy Industries instituted "Committee on Standardization of Protocol for Electric Vehicles" which framed draft standards for charging stations – Bharat EV charger AC – 001 and Bharat EV charger DC – 001.

The summary of the standards on charging stations are presented in Table 4.8.

Table 4.8: Summary of standards on charging stations

Standard Name	Description & Applicability	Global Reference	Point of Distinction
AIS 138 (Part 1)	For charging electric road vehicles at standard AC supply voltages (as per IS 12360/IEC 60038) up to 1000 V and for providing electrical power for any additional services on the vehicle if required when connected to the supply network. Applicable for 1) AC Slow Charging (230 V, 1 Phase, 15 A Outlet with connector IEC 60309) and 2) AC Fast Charging (415 V, 3 Phase, 63 A Outlet with connector IEC 62196)	IEC 61851 Part 1, 22; SAE J1772; GB/T 18487 Part 1,2,3	IEC 61851 has ambient temperature of -25 to 40 °C. For Indian condition AIS has suggested it 0 to 55 °C. CEA in its recommendations have suggested higher +60 °C.
AIS 138 (Part 2)	For DC EV charging stations for conductive connection and digital communication to the vehicle, with an AC or DC input voltage up to 1000V AC and up to 1500V DC (as per IS 12360/IEC 60038)	IEC 61851 Part 1, 23, 24;	
AC-001	It Presents the specifications of a Public metered AC outlet (PMAO) which is to provide AC input to the vehicle which has on-board chargers. This document applies to electric road vehicles for charging at 230V standard single-phase AC supply with a maximum output of 15A and at a maximum output power of 3.3kW. PMAO is a slow charger for low-power vehicles	IS 12360; IEC 60309;	
DC-001	It prescribes the definition, requirements and specifications for low voltage DC electric vehicle (EV) charging stations in India, herein also referred to as “DC charger”, for conductive connection to the vehicle, with an AC input voltage of 3-phase, 415 V. It also specifies the requirements for digital communication between DC EV charging station and electric vehicle for control of DC charging.	IEC 61851 Part 1,23; GB/T 20234.3;	

Separate and independent consultative committees formed under ARAI, CEA and ETD-51 (under BIS) has looked into charging and various EV testing standards.

- BIS has published Indian Standards (IS), IS: 17017 (derived from IEC 61851) which covers general requirements and safety for EVSE. Further parts of this standard are under review for both AC and DC chargers and shall be published shortly. The standards recognise Department of Heavy Industry (DHI) supported Bharat Chargers (AC-001 and DC-001) for low voltage EVs (less than 120 V). For higher voltage levels, the standard supports CCS-

2 and CHAdeMo. The standard also recognises CEA's recommendations for correcting India specific ambient conditions in range of 0 to 55 °Celsius.

- There are additional two different working groups within ETD-51 to decide upon connectors and communication protocol. Both these shall play important role to base interoperability of the chargers. There is intent in GoI to have custom low cost connector specific to Indian requirements and vehicle mode usage and there is an announced grand challenge to design the same. Until the results are published, the existing charging standards (Bharat Chargers, CCS-2 and CHaDeMo) are to be used as-is with existing connectors and communication.

- For communication between EVSE and EV, India has made decision to adopt ISO: 15118 as-is. BIS shall shortly publish IS: 15118.

4.5 Assessment of Draft Regulations on Interconnection and Safety Standards Prepared by Central Electricity Authority (CEA)

Central Electricity Authority (CEA) is a statutory agency functioning under the Ministry of Power, Govt. of India. CEA was originally constituted under Section 3(1) of the repealed electricity (supply) Act, 1948, since substituted by Section 70 of the Electricity Act, 2003. It was established as a part-time body in 1951 and made a full-time body in 1975. The functions and duties of CEA are clearly delineated under Section 73 of the Electricity Act, 2003.

More specifically, CEA has to discharge various other functions as well under Section 3 (National Electricity Policy & Plan), 8 (Hydro Electric Generation), 34 (Grid Standards), 53 (Provision relating to Safety and Electric Supply), 55 (Use of Meters) and 177 (Making of Regulations) of the Electricity Act, 2003.

In exercise of powers conferred by Section 177 of the Electricity Act 2003; the CEA issued the Regulations for Measures relating to Safety and Electric Supply, on the 20th Sept 2010.

1. These regulations mainly deal with following issues:

    - General safety requirements pertaining to construction, installation, protection, operation and maintenance of electric supply/ lines and apparatus
    - Precautions to be adopted by consumers, owners, occupiers, electrical contractors, electrical workmen and suppliers
    - Periodical inspection and 'Testing of Installations' by Electrical Inspectors
    - Precautions against leakage before connection and leakage on consumer's premises
    - Various tests for confirming safety provisions for electrical installations and apparatus, for voltage not exceeding 650 volts and exceeding 650 volts along with various Interlocks and protection systems
    - Clearances above ground of the lowest conductor of overhead lines and clearances from buildings for lines of voltage exceeding 650 V
    - Lines crossing or approaching each other and lines crossing - street and road: Clearances and other safety measures
    - Regulations for guarding, earthing, safety and protective devices
    - Safety issues, precautionary measures in laying of cables
    - Safety requirements for electric traction, mines and oil fields

2. Schedules in 2010 regulations and forms for field inspection report:

- Syllabus, duration of training for safety measures for operation and maintenance of electrical plants: Thermal Plants/Hydro Plants/Diesel Power Plants/Combined Cycle Gas Turbine based power plants for the operating engineers & supervisors, technicians (Mechanical, Electrical & Instrumentation)
- Syllabus for technicians, assistant engineers and supervisors in operation and maintenance of sub-station associated with the generating stations, T&D systems for lines and substation apparatus and assessment forms for assessing the impact of training
- Precautions to be followed in "handling of electric supply lines and apparatus" and tools normally required for hot line maintenance operation

4.5.1 CEA (Measures relating to Safety and Electric Supply) Amendment Regulations, 2015

The first Amendment to the CEA (Safety & Electric Supply) 2010 Regulations was notified on 13th of April, 2015. The salient features of the amendment regulations are the following:

- Defining duties of Electrical Safety Officer and Charted Electrical Safety Engineer
- Inclusion of mandatory provisions of earth leakage protective device: Supply of electricity to every electrical installation other than voltage not exceeding 250 V, below 2 kW and those installations of voltage not exceeding 250 V, shall be controlled by an earth leakage protective device, whose maximum earth leakage threshold for tripping should not exceed 30 milliamps for domestic connections and 100 milliamps for all other installations, so as to disconnect the supply instantly, on occurrence of earth fault or leakage of current
- Penalty for use of electricity at voltage exceeding notified voltage
- Electrical Inspector shall not authorise the supplier to commence supply unless-all conductors & apparatus situated on the premises of the consumer are so placed as to be inaccessible except to a designated person and all operations in connection with the said conductors and apparatus are carried out by a designated person.

4.5.2 Draft Safety Provisions for Electric Vehicle (EVs) Charging Stations

CEA's proposal is for amending the safety regulations to incorporate the provisions pertaining to charging of EV. The draft was circulated on 27th of April, 2018. Comments were invited up to 26th of May, 2018. These provisions apply to AC and DC charging points with standard A.C. supply voltages and D.C. supply voltages for providing power supply to EV.

Electrical safety is the most important issue at an EV charging station as it will be used by the common people, who may be unaware of the hazards due to unsafe operations and unsafe equipment. As such, the safety regulation for EV charging stations should be followed stringently.

1. General safety requirement for EV charging stations:
   - All EV charging stations shall be provided with protection against the overload of input supply and output supply.
   - Any socket-outlet of supply in EV charging station shall be at least 800 mm above the finished ground level.

- A cord extension set or second cable assembly shall not be used in addition to the cable assembly for the connection of the EV to the Electric Vehicle charging point. A cable assembly shall be so constructed that it cannot be used as a cord extension set.
- Adaptors shall not be used to connect a vehicle connector to a vehicle inlet.
- EV parking place should be such that the connection on the vehicle when parked for charging shall be within 5 metre from the EV charging point. (Note: maximum length allowed for the supply lead proposed should be of 5 meters)
- Portable socket-outlets are not permitted to be used for EV charging
- Suitable lightning protection system shall be provided for the EVs charging stations as per IS/IEC 62305.
- EVs charging stations shall be equipped with a protective device against the uncontrolled reverse power flow from vehicle
- Disconnection of EV: One second after having disconnected EV from the supply (mains), the voltage between accessible conductive parts and earth shall be less than or equal to 42.4 V peak (30 V rms), or 60 V D.C., and the stored energy available shall be less than 20 Joules (as per IEC 60950).
- If the voltage is greater than 42.4 V peak (30 V rms) or 60 Volt D.C., or the energy is 20 Joules or more, a warning label shall be attached in an appropriate position on the charging stations.
- Locking of the coupler: A vehicle connector used for D.C. charging shall be locked on a vehicle inlet if the voltage is higher than 60 V D.C. The vehicle connector shall not be unlocked (if the locking mechanism is engaged) when hazardous voltage is detected through charging process including after the end of charging. In case of charging system malfunction, a means for safe disconnection may be provided.
- Protection against overvoltage at the battery: The DC EV charging point shall disconnect supply of electricity to prevent overvoltage at the battery, if output voltage exceeds maximum voltage limit set by the vehicle.
- Verification of Vehicle Connector Voltage: EV Charging station shall not energize the charging cable when the vehicle connector is unlocked. The voltage at which the vehicle connector unlocks shall be lower than 60 V
- Basically, all these provisions in the draft regulations are necessary for the general safety of personnel and equipment at the EV charging stations.

2. Earth protection system for charging stations
   - All Residual Current Devices (RCDs) for protection of supplies for EVs shall have a residual operating current of not greater than 30 mA and shall operate to interrupt all live conductors, including the neutral.
   - All RCDs used for protection of supplies to EVs shall be permanently marked to identify their function & the location of charging station or socket outlet they protect.
   - Each EV charging station shall be supplied individually by a dedicated final sub-circuit protected by an overcurrent protective device complying with IEC 60947-2, IEC 60947-6-2 or the IEC 60269 series. The overcurrent protective device shall be part of a switchboard.
   - Where required for service reasons, discrimination (selectivity) shall be maintained

between RCD, protecting a connecting point and an RCD installed upstream.

- All EV charging stations shall be supplied from a sub-circuit protected by a voltage independent RCD & also providing personal protection that is compatible with a charging supply for an EV.
- All EV charging stations shall be provided with an Earth Continuity Monitoring System that disconnects the supply in the event that the earthing connection to the vehicle becomes ineffective.
- Earthing of all EV charging stations shall be TN system (system of isolation during emergency) as per IS 732 (Standard Code of Practice for Electrical wiring)
- A protective earth conductor shall be provided to establish an equipotential connection between the earth terminal of the supply and the conductive parts of the vehicle. The protective conductor shall be of sufficient rating to satisfy the requirements of IEC 60364-5-54.

3. Requirement to prevent fire in EV charging stations
    - Fire-fighting system for EV charging stations shall be as per relevant provisions of CEA (Measures Relating to safety and Electric Supply) Regulations 2010. Fire detection, alarm and control system shall be provided as per relevant IS
    - Enclosure of charging stations shall be made of fire retardant material with self-extinguishing property and free from halogen

4. Testing of EVs charging stations:
    - All apparatus of EV charging station shall have the insulation resistance value as stipulated in the relevant IEC 61851-1.
    - Testing as specified in the manufacturer's instructions for the RCD and the EV charging Station, has to be carried out at site

5. Maintenance of Records
    - EVSE station will be tested and inspected by the owner/Electrical Inspector/CESE. It is necessary to keep records regarding the design of EV charging station
    - It is also mandated to keep records of the relevant test certificates, as per IEC 61851 standard

6. Periodic maintenance & assessment of EV charging stations:
    - An EV charging station operator shall arrange periodic test/inspection of an EV charging station by Electrical Inspector/CESE for every four years
    - The owner/operator shall establish & implement a safety assessment program for regularly assessing the electrical safety of EVSE, conductors and fittings
    - Owner/operator shall keep records of the results of every periodic assessment and details of any issues found during the assessment; any actions required to be taken in relation to those issues shall be carried out
    - The owner/operator shall retain a copy of all records, either a hard copy or an electronic copy, for at least seven years and shall provide a copy of the records to the inspecting officers

7. International Standard for charging stations

As per the draft proposal the following International Standards need to be followed:

- Safety provisions of all A.C. charging stations shall be in accordance with IEC 61851-1, IEC 61851- 21, IEC 61851-22 and IEC 61851-24.
- Safety provisions of all D.C. charging stations shall be in accordance with IEC 61851-1, IEC 61851- 21, IEC 61851-23 and IEC 61851-24
- Where the connection point is installed outdoors, or in a damp location, the equipment shall have a degree of protection of at least IPX4 in accordance with IEC 60529.

The Draft Safety & Supply Regulations circulated by the CEA in May 2018, are generally based on International Standards and cover all relevant aspects of electrical safety in EV charging stations.

4.6 Efficient Frameworks of Policies and Regulations

India is different than most currently EV progressive countries in terms of its transport mode usage (70% 2-Wheeler dominance); acceptable vehicle models (measured in features, performance, cost); road and traffic conditions; automobile and EVs supplier ecosystem; Government structure between Central, State and City and respective efficiency; DISCOM Utility structure and performance; most importantly its end-users demographics, behaviors and affordability. All these shall affect choices that India needs to make to define and execute its EV roadmap. Some key elements to build right policy and regulation structure for scaling-up EV adoption in India can be as below. This is not a comprehensive list, but shall serve as guidelines to build the right framework.

Define clear targets	• What EV % penetration levels in new sales across different vehicle segments (2W, 3W, 4W, buses, trucks) and by what time frames (2020, 2025 and 2030) • Further segmentation and different use cases (personal vs. commercial vs. govt. fleet, passenger vs. goods, urban vs. rural) etc. should be defined as breakup of above targets • Selection of right technologies (BEV vs. PHEV vs. Hybrid vs. Fuel cell and any other alternate fuels) • % Mix of fast chargers (with appropriate high level specs)
Increase electrification & adoption of public transportation	• Setting higher and stricter EV conversion timelines for public transportation (buses (intra-city and inter-city), 3Ws, 4Ws taxi, etc.) • Supporting Viability Gap Funding (VGF), if needed, for any higher cost of EVs use in public transportation • Rationalizing tariffs for public transport to provide higher quality services • Specialized cash backs for using EV fleet rides

Incentivise customers for EV purchase (and also retrofits) – for individual, fleet and Govt. applications	• Ease of Approvals o Ease of permits, transfers and ownership of EVs o Remove caps for all EV fleets (like for 3Ws, etc) o Allow corporate/business ownership for EV fleet (like for 2Ws, 3Ws, 4Ws etc.) • Lower Purchase Cost: o Subsidies on purchase of EVs (with clear phase-out timelines) – Central and State o Reducing GST charges on EVs - Central and State. (Other options like tax credits can also be looked) o Special incentives and relaxation for vehicle registration charges and taxes o Scrap guidelines and incentivized price for replaced ICE vehicles in exchange for EVs o Support retrofit EVs • Ease and lower cost of Financing: o Making attractive for Banks to fund EVs (Example: making EVs part of priority sector lending) o Subsidise/ reduce interests on EV financing. Also, down payment subsidy can be looked. o Allow accelerated depreciation for EVs • Ease and lower cost of Operations: o Easy availability and access to charging be it home, office, street parking, petrol station, other public charging sites, highways etc. (Example: MOP guideline for public charging infrastructure every 3 sq. kms; 20% parking allocation for EVs, for new buildings as per new revised Building code) o Lower cost to EV charging through: o reduced GST on charging services o making power connection and electricity available at reduced tariffs for EVs o Reduce toll charges, parking fees, entry tax, etc. for EV users o Extend other soft benefits for EV users (Example: preferred EV or Zero Emission lane/town-centre/parking spaces etc.) o Reduction of car insurance and other charges
Penalize behaviors to drive important changes	• Target and cap on new additions to ICE vehicles (specially fleet like 3Ws, 4Ws, buses etc.) to cities • Levying additional user charges/cess/ tax on continue use of ICE vehicles towards 1) pollution, 2) road use 3) parking charges etc.

Incentivize setting up Charging Points/ Stations (and other EVs Investment)	• Fleet charging o Encouragement for fleet charging with required incentives for EV charging connections at large apartments and companies will help to increase high penetration of EVs in the system. • Lower Charging setup cost o Subsidy to purchase and installation of EV chargers for all types of chargers (AC and DC) across locations home, office, on-street, public charging, malls etc., including battery swapping charging stations o Reducing GST charges on EV Chargers, Lithium-Ion Batteries (LIB) & charging stations - Central and State. Also reduce any import duty, if any. o Supporting land allotment on long lease for EV charging setup • Ease and lower cost of Financing: o Making attractive for banks to fund EV charging infra o Subsidise/reduce interests on EV charging infra financing o Incentivize DISCOMs to own and setup EV charging stations • Lower electricity cost (discussed separately) • Preserving market competitiveness • Allowing market governed pricing structure for EV charging services (and no caps)
EV charging with Renewables	• New development of strategies can be adopted to charge the EVs with different ways and at different times. Roll out of policies at initial stage of EV penetration with usage of renewable energy sources (Wind and Solar) anywhere in the grid for EV charging will help to minimize the carbon footprints. For example, shifting of charging time of EVs at night time when high share of wind is available in grid and or during day time when high share of solar generation is available in grid will make system optimal.
Rationalizing EV Charging Electricity availability, and tariffs	• Access and Availability o SLAs from DISCOM for timely connection release for EV charging at all locations o Allowing pooling of connection loads for EV charging stations at a city level for allowing open access • Use of Renewables, Energy Storage and V2G o Special incentives for sourcing of renewable power for EV charging o Additional special incentives for peak load optimization to charging stations (through use of technologies – energy storage, others) o Additional special incentives for support to grid balancing for V2G use in charging stations • Tariffs o Time of unit tariff or dynamic charging prices o Special incentivized electricity tariffs for EVs charging to all users – home/ society, office, on-street, public charging, malls etc. o Reduce or nullify demand charges o Allow time of use charges for all different categories of EV users o Wave-off electricity duty or other levied taxes on connections adding EVs o EV electricity tariffs should be rationally agreed and not to add to DISCOM losses

Raising EV pooled funds & programmatic financing	• State/City can raise EV pooled funds (as suggested in Delhi EV policy). It can source funds through, o Charging penalties for continue use/add of ICE vehicles o ICE Vehicle OEMs to be charged for cumulative emissions (which they in-turn charge to end-user) o Build right carbon abatement instrument and its tradable market
Supporting healthy EV Supply Ecosystem Built-up (Make in India)	• Standards o Bringing speed and clarity on EV and charging related standards (including connectors and communication protocols). For the big market India to become in EVs, India can consider going for its custom Bharat charger standards for AC and DC chargers across all ranges of vehicle segments. • Taxation o Reduced GST slab on all inputs and final assembled product or full EVs (and keeping this same across all) o Clear guidelines for import/custom duties to be able to bring right new technologies and equipments at lower cost, but then gradually phasing this out (to allow country eco-system growth) o Clear guideline to help India OEMs to emerge as favorable EVs export to globe • Investment o Capex, Opex and interest subsidy for EVs or related manufacturing setup o Allow capitalize R&D investments in EV related technologies and providing tax benefits
Strong Grid Upgradation and Management	• Clear standards for chargers and grid interconnectivity and communications for grid stability, safety, and transaction • Common agency to have all charging data via DISCOMs to plan required grid strengthening and management • At the present state of India, with very minimal EV infrastructure & vehicles (minimal chances of usage of full control with smart charging) and considering the loading of urban feeder ranging from 75% to 95%, there is need to move funds for upgradation of network components. • This initial upgrades and implementation of full control of smart charging including V2G will help DISCOMs to manage the high EV penetration in the future years.
Lithium Battery Promotions and Market Development	• Stricter environmental guidelines to phase-out lead acid batteries use • Guidelines for LIB recycling and creating market for secondary life-cycle use and battery recycling • For Lithium security, import of old LIBs for recycling and creating right guidelines for same

All three levels of central, state and cities will need to work together to seamlessly allow market to develop and adopt increase use of EVs.

4.7 Recommendations to BYPL

4.7.1 Public Charging Infrastructure Investments

- Public charging investment is high, with a risk of lower utilization in initial years of adoption. However, DISCOM should leverage their sub-station and office land holdings to setup public charging infrastructure, either by self-investment or in partnership with private operators. The following are the investment options available:
    - o SERC (State Electricity Regulatory Commission) allows capitalizing Public charging infra investment to DISCOM: In this case, DISCOM should invest in setting up and operating public charging infrastructure.
    - o Allow DISCOM to avail subsidies for public charging infrastructure: There is up to 100% capital subsidy for setting up charging infrastructure under FAME-II. DISCOM can avail these benefits and setup dedicated bus charging and public charging setups.
    - o Strategic partnership with private operator: If any private charge point operator or electric fleet operator is willing to invest in charging infrastructure by using DISCOM's land holdings with easy and reliable electrical connection access, then that could still be a good partnership to learn and sell more kWh units.
- DISCOM can prioritize supporting commercial EV fleet charging to de-risk lower utilization in early years. This includes e-Buses, e-3Ws and e-4W cabs. General public charging stations investments should be made cautiously leveraging subsidies and keeping OPEX costs low.
- Additionally, DISCOM should strengthen its grid inter-connection process, communication, and services to its own or third party invested EVSEs. This enables it to build its value as a back-end player that controls flow of power to the EVSEs through some form of controlled/ managed charging to maintain the grid balance and avoid any collapse.

4.7.2 Home and Work/Office Charging Infrastructure Support

- Home and office charging both combined shall take most of the load in terms of the total no. of EV charging transactions and also by kWh consumption.
- DISCOM, with its reachability and customer connect can become the primary service provider to install quality EV chargers at homes and offices thereby enabling more kWh consumption.
- There is an opportunity for DISCOM to partner with Home/ Office charger OEMs to develop a new meter integrated smart AC charger that differentiates EV consumption thereby allowing differential billing. A more advance integration of solar related net/gross metering can also be embedded in this new device.
- DISCOM to establish and recommend a standards Committee for high quality off-board chargers for home and office AC charging for higher person and grid safety.

4.7.3 Battery Swapping

- Battery swapping shall involve high investments in batteries and this may not be the core business for DISCOM. However, DISCOM can support through its land holding in sub-stations etc. to private investors that want to set-up battery swapping and bulk charging centers and also support with high quality LT or HT power.

4.7.4 Electricity Tariffs for EVs

- There shall likely be a continuous change in electricity tariffs around EVs in months and years to come. It is noteworthy to mention that Delhi EV tariff policy and policy makers are progressive. DISCOM should support implementing the changes to favor easy adoption of EVs by masses.
    - Delhi is the first state to announce separate EV Tariff category
    - Extended EV category electricity single-point tariff of Rs. 5.5/kWh to home, office and another type of charging locations (in addition to public charging)
    - The EV Tariff set for the next 5 years can only reduce but not increase
- DISCOM can request SERC to allow capitalization of public charging stations, including the battery swapping charging stations. In it, it should include both society common charging stations and public parking charging stations.
- DISCOM should pursue regulations for driving TOU tariffs for EV charging at public, private fleet and battery swapping bulk charging stations.

05

System Data for EV Impact Study

BSES Yamuna Power Limited (BYPL) has shortlisted about 12 feeders emanating from different grid substations under its jurisdiction with the objective to select 3 feeders (+ 1 feeder with dedicated charging stations for public bus transportation) for simulation studies. The simulation studies will provide the guidelines to find the impact of EV charging infrastructure on distribution grid. The development of various scenarios of charging stations on the 3 selected feeders plays an important role to understand the impact of EV on grid for future years. The studies include solar roof top and energy storage system, and analyse the effects of additional loads from the electric vehicle charging stations on the selected feeders. The effects studied include change in voltage regulation, loading of feeder, loss and harmonics in the feeder.

5.1 Feeders Shortlisted by BYPL

Project team has communicated the required data for selection of 3 feeders with BYPL before the project team visit to BYPL on 13th and 14th Dec 2018. 13 feeders were shortlisted by BYPL before the site visit and same is presented in Table **5.1.1**.

Project team has visited BYPL Distribution company on 13th and 14th December 2018, to understand the distribution operation and data availability at various departments in BYPL like, Energy accounting, SCADA, GIS etc. Project team and BYPL engineers had extensive discussions to finalize the 3 feeders out of 13 feeders.

Table 5.1.1: Feeders shortlisted by BYPL

Name of the Feeder	
1.	Arya samaj road nalha
2.	DDA flats pocket B
3.	DSR Mill
4.	E block Vikas Marg
5.	Janta Colony
6.	Karkardoma Court
7.	Karol Bagh - 2
8.	Parade ground
9.	District Center EROS Hotel
10.	Vikas Bhawan
11.	IHBAS Mental hospital
12.	Marjinal Bandh
13.	MVR Sadar

The criteria considered for the selection was discussed with BYPL engineers and after rigorous study of the data available and discussions on the shortlisted feeders, 3 feeders were selected for simulation studies in Jan 2019.

Various possibilities are discussed like simulation of rooftop PV penetration, EV charging stations, various impact studies etc.

5.2 Data Collected for Shortlisted Feeders

In order to select suitable feeders for the analysis, a set of data was requested to BYPL for the shortlisted feeders. The data collected to select 3 feeders are furnished in Table 5.2.1.

Table 5.2.1: Data collected for the shortlisted 10 feeders to converge on 3 feeders

Feeder load profile for a year
Feeder load growth for the past 5 years
Feeder voltage profile for a year
Number of DTs on each feeder
DT capacity (kVA)
DT phase wise loading for a year
DT phase wise voltage for a year
Consumer mix connected on each DT
Monthly energy consumption on each DT for a year
DT wise monthly peak for a year
Location and capacity of existing domestic EV charging stations in the feeder

5.3 Criteria for Selection of 3 Feeders

Based on the detailed discussions with BYPL and considering both technical and other critical parameters are considered to shortlist the feeders and same is furnished in Table 5.3.1. The basic details of each feeder are presented in Table 5.3.2.

Table 5.3.1: Criteria considered for selection of 3 feeders

EV charging stations existing in the feeder
Solar roof top penetration in the feeder
Loading of the feeder
Voltage profile of the feeder
Priority for public charging locations, parking facilities, sites along high-traffic corridors, in shopping centres, at grocery stores, and other such locations
Priority for Level 2 chargers and DC Fast Charging locations in feeder area
DT loading in the feeder
Consumer mix in the feeder
Monthly energy consumption in the feeder

Table 5.3.2: Basic Data of the Feeders

Sl. No	Name of the Feeder	Peak load in a year (MW)	No. of DTs in feeder	Total DT capacity in feeder (kVA)	Total no. of consumers connected	Max energy consumed in a month (MWh)
1	Arya samaj road	4.3	6	5940	4977	2112
2	DDA flats pocket B	3.52	13	6350	1851	993
3	DSR Mill	4.84	6	5220	3634	1567
4	E block Vikas marg	3.6	3	2970	1598	865
5	Janta Colony	3.81	10	5840	3767	1941
6	Karkardoma Court	4.3	2	1260	409	122
7	Karol Bagh - 2	4.85	8	6970	3392	1762
8	Parade ground	1.19	3	2250	898	370
9	District Center EROS Hotel	1.223	1	400	3	5
10	Vikas Bhawan	2.46	-	-	-	-
11	IHBAS Mental Hospital	-	-	-	-	-
12	Marjinal Bandh	-	-	-	-	-
13	MVR Sadar	5.64	25	14370	2027	1270

5.4 Selected 3 Feeders

Summary of feeders with reference to various selection factors are presented in Table 5.4.1.

Table 5.4.1: Feeders not meeting the criteria

S. No	Name of the Feeder	Roof top	Existing EV	EV preference
1	Arya samaj road	X	X	✓
2	DDA flats pocket B	✓	X	X
3	DSR Mill	X	X	X
4	E block Vikas arg	X	X	X
5	Janta Colony	X	✓	✓
6	Karkardoma Court	X	X	X
7	Karol Bagh - 2	✓	✓	X
8	Parade ground	X	✓	X
9	District Center EROS Hotel	X	X	✓
10	Vikas Bhawan	X	X	X
11	IHBAS Mental Hospital	✓	X	X
12	Marjinal Bandh	X	X	X
13	MVR Sadar	✓	✓	✓

Note: Solar PV rooftop generation of IHBAS Mental Hospital feeder is simulated on selected feeders to find the impact of solar rooftop generation.

After scrutiny of the provided data, consultation and discussion with BYPL, 3 feeders satisfying most of the criteria mentioned in Table 5.3.1 are selected for simulation studies with additional one dedicated feeder for charging of public transport. The selected feeders and major consideration in selection of each feeder is furnished in Table 5.4.2.

Table 5.4.2: Selected 3 feeders

Selection of Feeder	Selected Feeder Name	Major Selection criteria considered
Feeder-1	Janta Colony	EV charging stations for e-rickshaws exist in the feeder and also feeder is loaded about 69%.
Feeder-2	Arya Samaj Road	Voltage profile was recorded as low as 200 V at last DT location and also feeder is loaded around 76%.
Feeder-3	MVR Sadar	Other important parameters and locational importance DC charging stations are about to roll out in the feeder area

Feeder 1, Janta colony: Feeder has large number of existing e-rickshaws and hence more domestic charging stations. The feeder is loaded around 69%. Analysis on this feeder provides the impact of installation of EV charging stations on heavily loaded feeder and the up gradation requirement in the distribution network to accommodate planned EV charging stations in the future. Geographical location of Janta colony feeder map is presented in Figure 5.4.1.

Feeder 2, Arya Samaj Road: The feeder is heavily loaded around 76% and tail end voltage recorded is as low as 200V at LV side of tail end DT, the effect of voltage regulation of the feeder on the EV charging station and the effect of installed EV charging station on the tail end voltage of the feeder shall be assessed. Geographical location of Arya Samaj feeder map is presented in Figure 5.4.2.

Feeder 3, MVR Sadar: BYPL has planned to install public DC charging station and/or pubic mall/parking chargers on this feeder considering the locational importance. The feeder has large consumers with lot of parking places and good amount of PV generation. Geographical location of MVR Sadar feeder map is presented in Figure 5.4.3.

Feeder 4, dedicated feeder for Electric bus charging station: Additional dedicated feeder (proposed feeder) is selected to study the behaviour of the feeder, used to charge public transport vehicles.

The results obtained from the simulation studies for the selected feeders are extrapolated at DISCOM level.

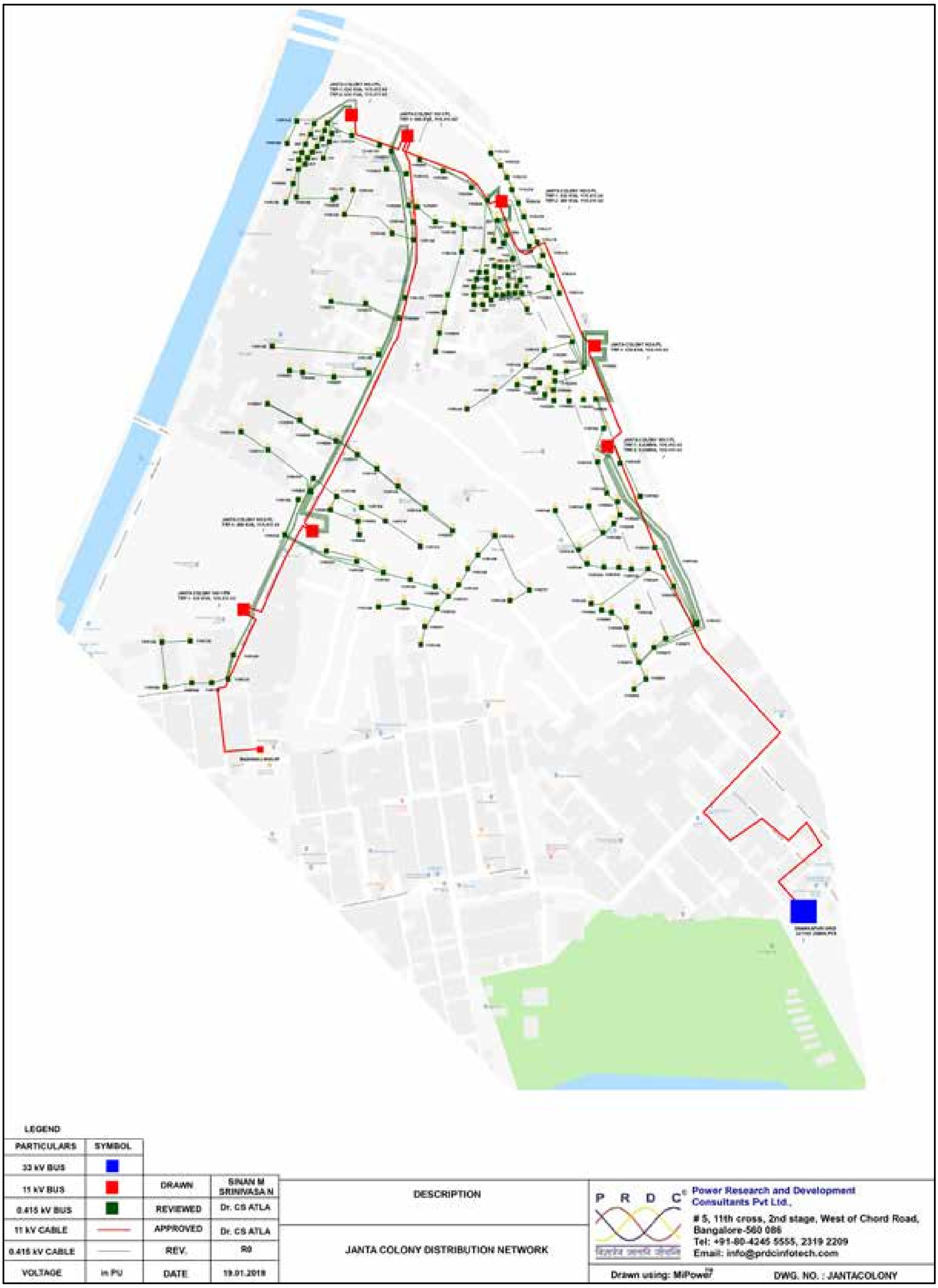


Figure 5.4.1: Geographical location of Janta colony feeder

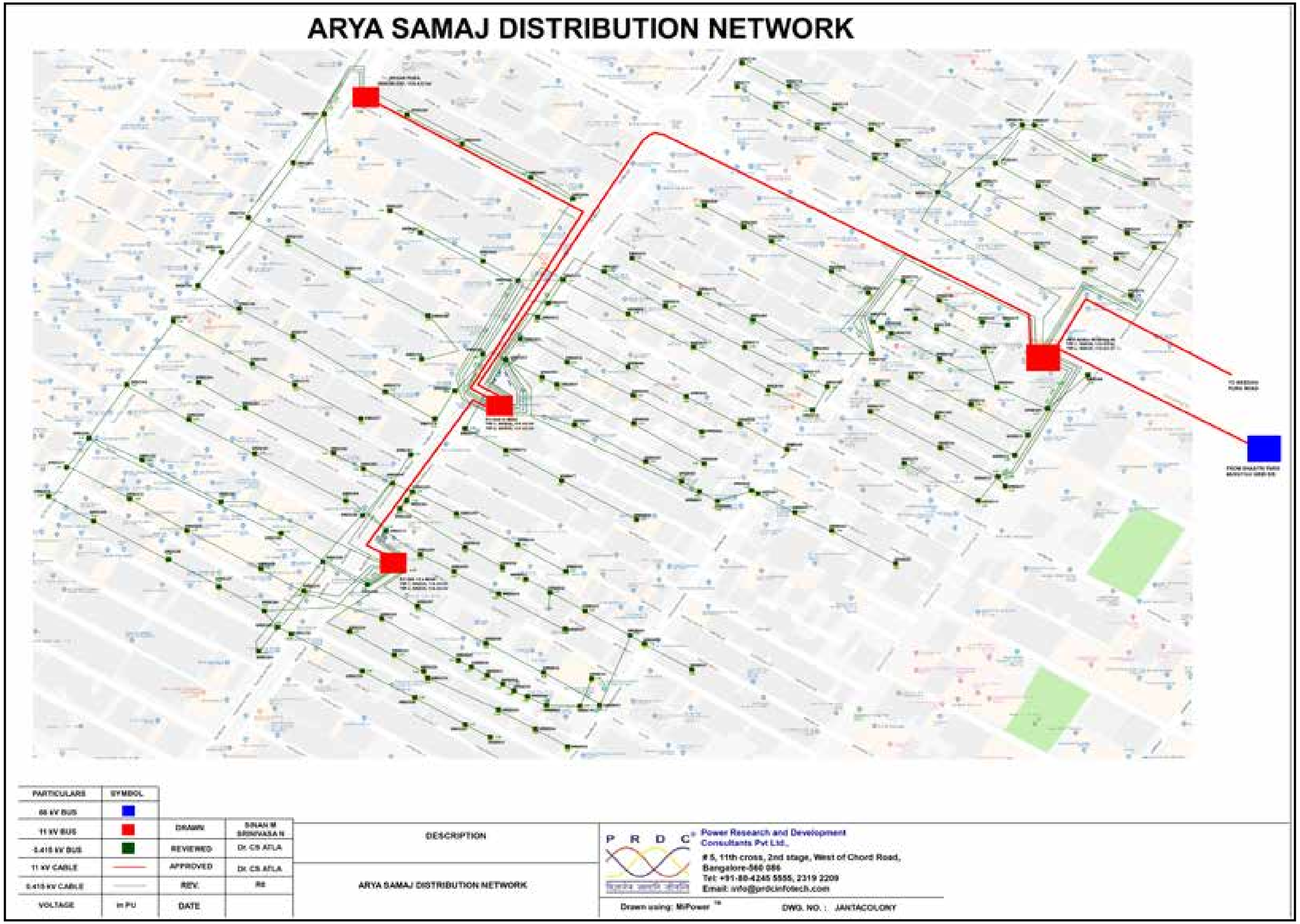


Figure 5.4.2: Geographical location of Arya samaj feeder

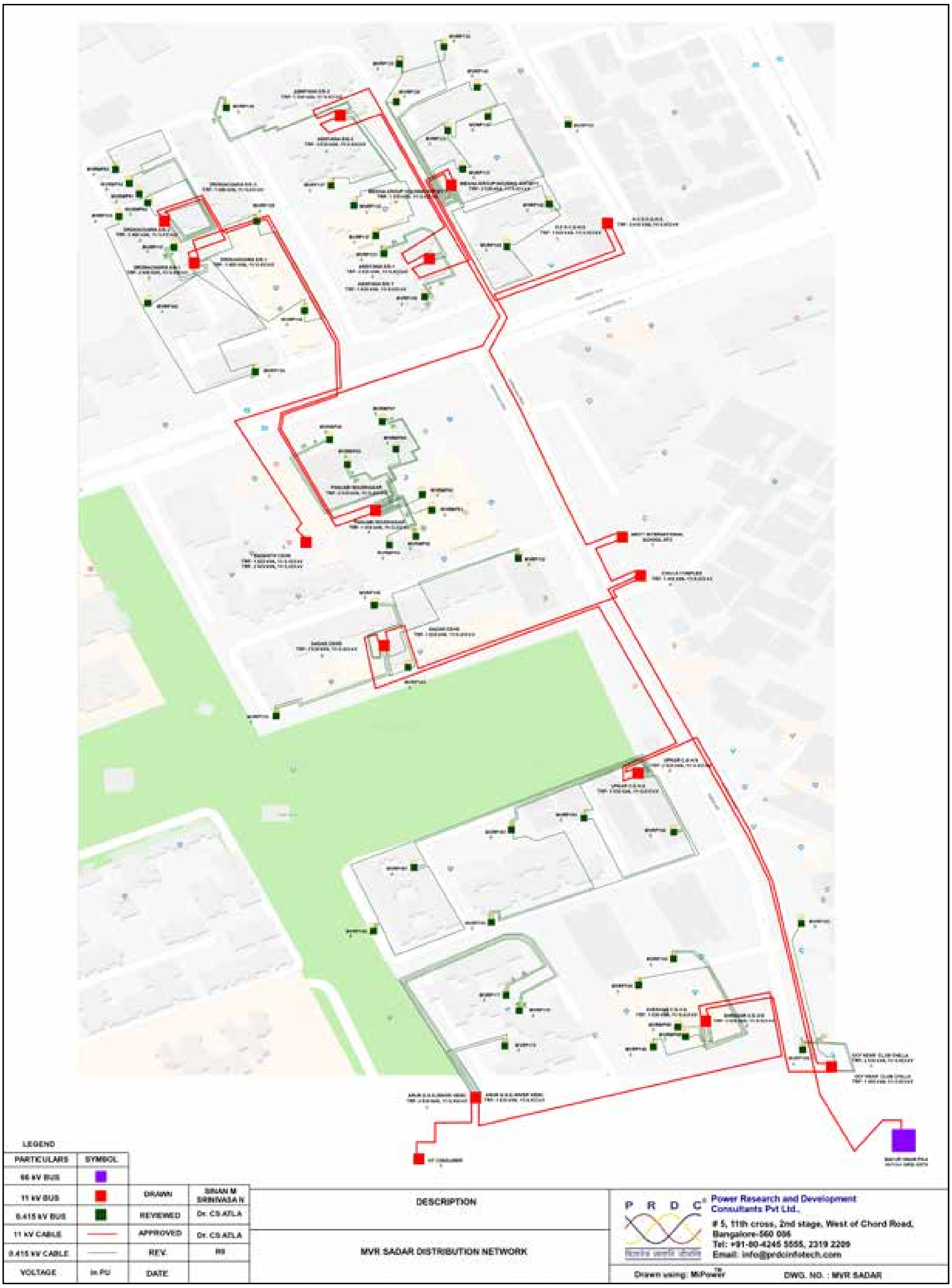


Figure 5.4.3: Geographical location of MVR Sadar feeder

5.5 Assumptions for Unavailable Data in Selected Feeder

Despite the fact that most of the data requested were provided, the feeders did not satisfy all the criteria considered to be selected. In such case, the data unavailable was assumed based on the similar data available on the other feeders in BYPL distribution network. Data which are assumed are furnished in Table 5.5.1.

Table 5.5.1: Data assumed

Harmonics	Typical harmonics generated by existing EV charging stations at a sample location is considered for simulation. Sample harmonics collected by the project team, measured from multiple sites with different Solar rooftop PV and industrial loads has been incorporated in the simulations.

5.6 Data for Selected 3 Feeders

This following detailed data is considered for the modelling and analysis of selected 3 feeders:

1. Network data for LT network (shape file) under DT for all selected feeders.
2. Network data for HT network (shape file) up to grid substation (of respective selected feeders), up to 33 kV or 66 kV bus including 33/11kV or 66/11 kV substations.
3. Type of the customers, number of customers and their connected load at each LT network pole.
4. Harmonic measurements at EV charging stations and roof top solar generation.

5.6.1 Harmonic Measurements at EV Charging Station

The sample harmonic measurements taken at one of the DISCOMs in India are presented for reference, to know the charging behaviour of Electric Vehicle. The charging station layout with harmonic meter connection is presented in Figure 5.6.1. The meter is connected at 415 V of the feeder near the charging station. The EV charging station consists of 3 charging modules, 2 of which are DC chargers of 15 kW each and an AC charging module of 3.3 kW. During the measurement period, one EV with 15 kWh battery capacity was plugged in around 12:00 PM to 1:30 PM with an initial SOC of 28% (Charging equipment was switched off twice in the plugged in period hence dip is observed in the characteristics). The waveforms of active power, reactive power, current, voltage and current harmonics observed in the period of EV charging are presented in Figure 5.6.2 to Figure 5.6.6.

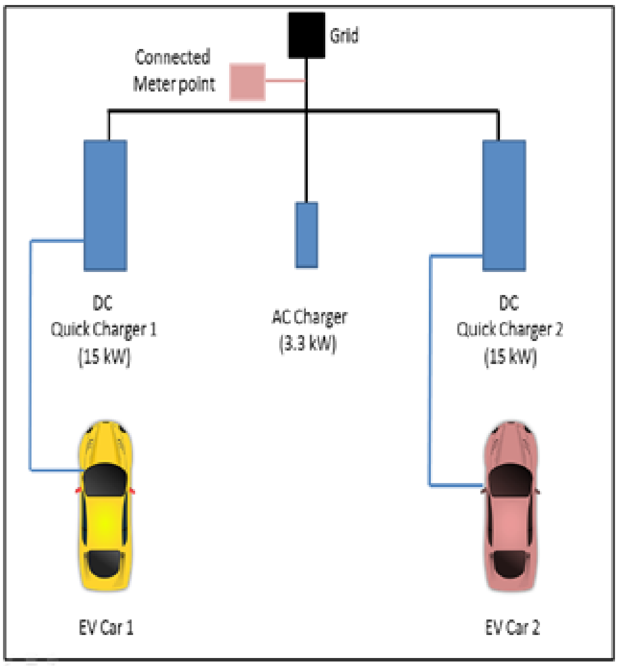


Figure 5.6.1: EV charging station layout

Figure 5.6.2: Three phase active power observed during EV charging period

Figure 5.6.3: Three phase reactive power observed during EV charging period

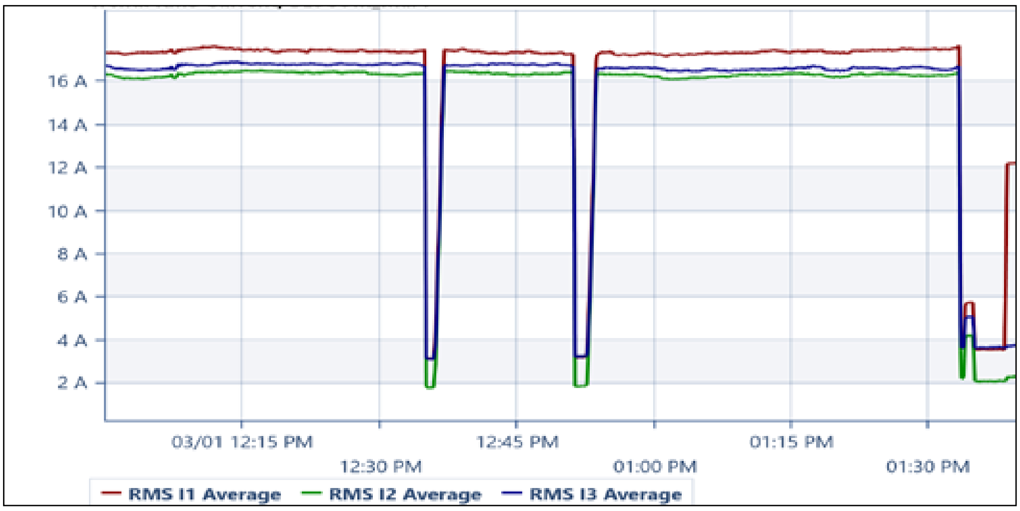


Figure 5.6.4: Individual phase current drawn during EV charging period

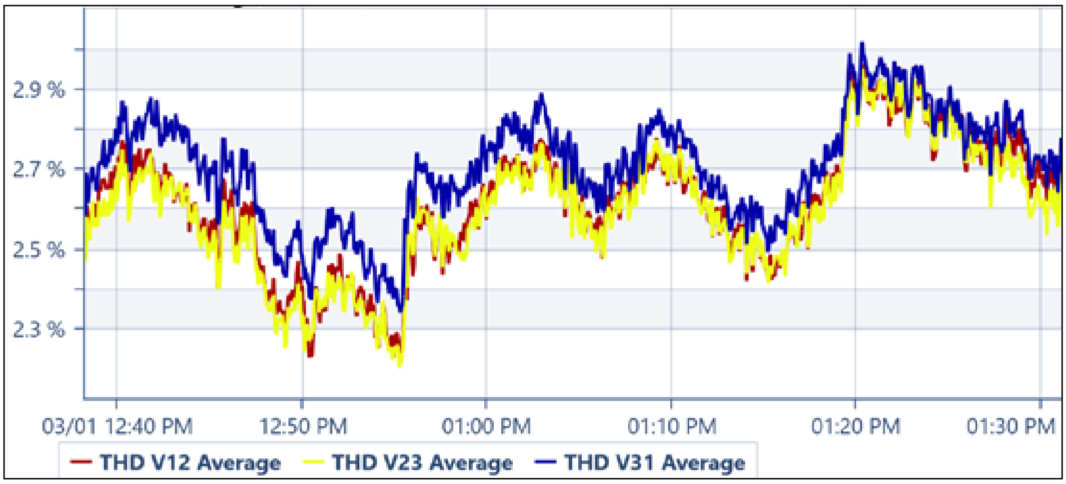


Figure 5.6.5: Total voltage distortion in % during the charging period

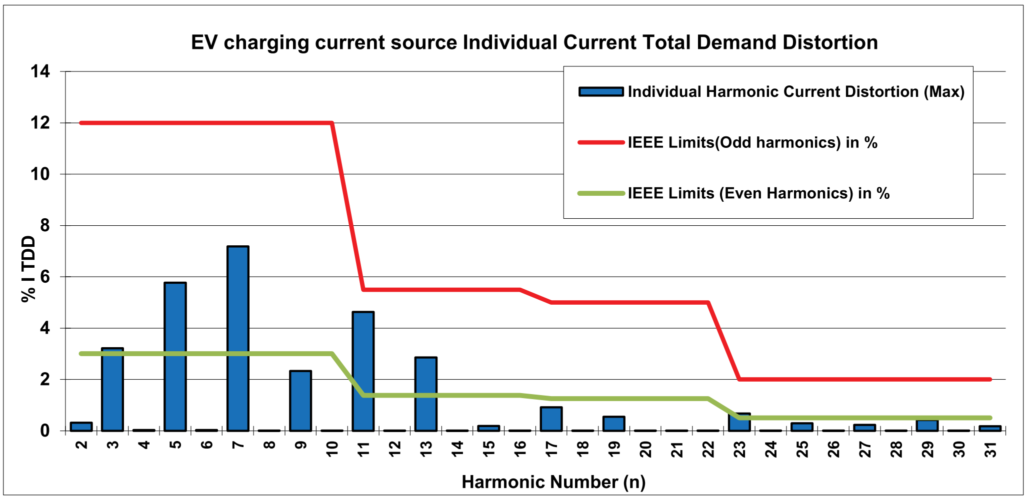


Figure 5.6.6: EV public charging station current harmonics

When EV is plugged in, a power of around 12 kW is drawn with a peak of 16 A in each phase and a reactive power of 3.3 kVAr. Power factor of around 0.95 is maintained while the EVs are charged. When the EV is connected to DC fast charger, average THD is observed is around 2.6% which is within the IEEE prescribed limits. Individual Current harmonics generated by EV charger are within the IEEE limits.

06

Methodology for Simulation Studies

This section develops the methodology to perform simulation studies to find the impact of EVs on distribution system for next 10 years, up to 2030.

To analyse the effect of EV charging stations on the feeders, load flow, dynamic and harmonic studies were performed on the modelled network.

6.1 Methodology for EV Charging Modelling Scenarios

The study methodology has been designed to find the near term and long term distribution impacts in response to customer behaviour and EV penetration along with solar roof top PV generation.

EV charging demand is evaluated by system-wide EV charging demand projections with approximate analysis, which is used for the charging profile of all EVs in the system. This method of estimation is used by utilities in evaluating impacts of EV integration on the power system, to upgrade the distribution system (including transformers, cables, and protection devices).

Electricity usage by EV is also affected by the driving behaviours and vehicle traffic conditions in addition to the range of the vehicle, state of charge of battery, distance travelled, size of the battery, current rating of the battery, battery characteristics. Users can charge their EVs at any charging facility in the system, which adds randomness to the demand characteristics. Moreover, EVs can start or terminate the charging process at any time of the day with various charging durations, depending on the travelling schedule, user preferences, etc.

In order to model the EV charging demand, five subsystem models are used in tandem. These models are

1. **Travel pattern model**- The travel pattern model captures the driving behaviours of EV users. Distances covered by EVs and the number of simultaneously charging EVs at each charging facility are the output of this model. Based on the Delhi policy, MoP guidelines and understanding, various scenarios will be generated under this category.
2. **Energy consumption model** - The energy consumption model characterizes the state of charge (SOC) of EV batteries at the starting time of charging process. Based on the type of EV vehicle technologies and EV charging station technology and charging port capacities, various scenarios will be generated under this category.
3. **Power consumption model**- The power consumption model estimates the charging power of the aggregated EV load profiles at the charging locations. Under this scenario, impact of charging characteristics and power at the start of EV charging and duty cycles will be captured in the scenarios.

4. **EV Penetration Levels**- EV penetration levels like 5%, 10%, 30% for next up to 10 years will be captured in various scenarios
5. **EV Charging Strategy-** Dumb charging, controlled/timed charging, fleet charging, load limit (feeder/DT) charging will be analysed in scenarios

Considering the system-wide EV charging demand projections and the subsystem models, number of scenarios are devised to capture the effect of different types of charging routines on the distribution system. The scenarios are:

- Workplace commuter charging - Employee charging at workplaces is likely to account for most charging at commercial and industrial sites in the near future. This load will be part of the peak load that occurs during day.
- Car park business – Offering public EV charging infrastructure is a natural model for car park businesses. Considering the likely future levels of utilisation of EV charging stations, this model will positively sustain.
- Car park at a shopping or leisure site - Supermarkets, shopping centres, sports centres, cinemas and other destinations with their own car parks could install EV charge points to persuade consumers to choose them over competitor destinations and spend more time and money on site.
- Overnight fleet charging - Depending on the types of vehicles, fleet electrification and overnight charging is a possibility.
- Roof-top solar generation- Feeder level roof top solar generation with its variability in nature source and its diversity throughout the feeder has an impact on location and type of charging stations in the feeder.
- Solar with energy storage: To make the most of this combination, the solar energy captured at peak times exceeds the EV energy demand with significant margin that the excess energy can be stored and can fully meet the energy demand over the evening demand peak.

The methodology is developed with combination of above scenarios with different types of charging stations at different locations of the feeder.

The process flow of EV charging scenarios with grid impact study is presented in Figure 6.1.1.

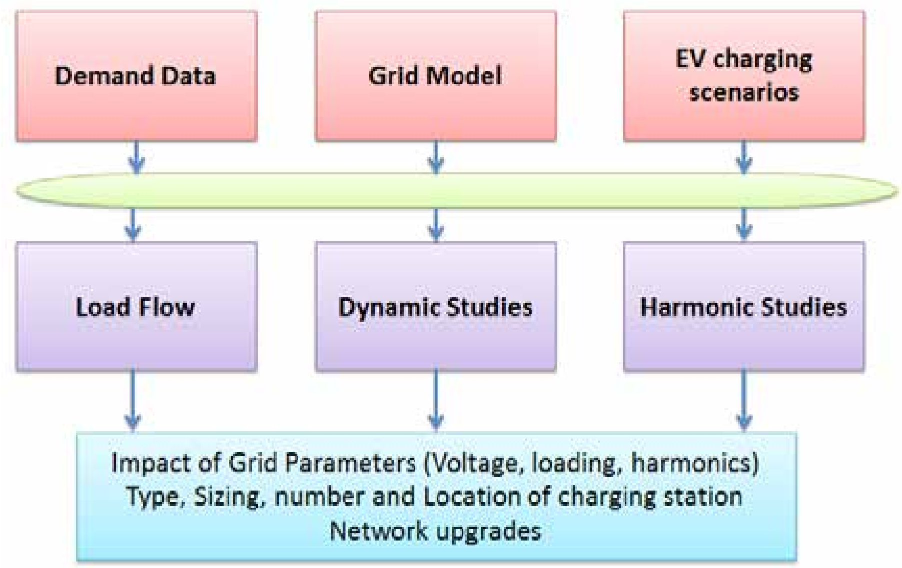


Figure 6.1.1: Process flow of EV impact studies

Further, data statistics for development of scenarios and methodology to calculate the number of charges occurring under each selected feeder per day is provided in sections 8.1 and 8.2 of annexure respectively.

6.2 Methodology to Extrapolate the Results of the 3 Feeders at DISCOM level

The objective of this phase is to synthesize the results of the 3 feeders and extrapolation of the results to BYPL / Delhi Distribution region.

The following points are considered while performing the aggregation of impact of EV charging at DSICOM level.

1. Peak demand and energy projections of DISCOM
2. Type of customers, number of connections in DISCOM area
3. Impact of EV capacity, type of EVs, its growth
4. Impact of the electrical vehicles on the electricity demand.
5. Impact of Grid technical parameters like loading of feeders and DTs, voltage regulation and harmonic levels
6. Factors that influence the number and location of charging stations
7. Impact of rooftop solar generation on EV charging infrastructure
8. Upgrades required for Feeder network to accommodate the EV charging infrastructure
9. Smart control charging strategy
10. Mitigation measures to improve the EV charging

07

Modelling of EV Charging Infrastructure

The study focuses on the large scale EV penetration and its impact on the distribution network. Three feeders (Janta Colony, Arya Samaj road and MVR Sadar) selected in BYPL network are used to assess the impact of EV charging on the grid. The study is performed for the years 2019, 2023 and 2030. The year 2019 is selected to assess the impact on the system due to EV charging on the present network condition, years 2023 & 2030 are selected as these are the major focus years where the EV sales targets are set by Niti Aayog [61] [63]. Solar rooftop penetrations in the feeders are considered for the years 2023 & 2030 as per the goals set by MNRE [66] and the maximum rooftop solar penetration limit under DTC has been considered as per [67].

To simulate electric vehicle load on the feeder, plug-in at different time slots at different charging locations with corresponding charging rates are considered as per the methodology presented in previous section. A typical load profile is selected for each feeder on peak demand season based on the historical data and the simulations are performed for 24 hours to assess the impact of EVs on feeders with and without PV generation for the years 2019, 2023 and 2030.

7.1 Battery Model in MiPower™

Battery model capability of MiPower™ is used for the analysis as shown in Figure 7.1.1. Parameters considered for the model are listed below,

a. Rated voltage of the battery
b. Rated current of the battery
c. Initial SOC- Initial state of charge of the battery
d. Rate of charge and rate of discharge
e. Charging curve - SOC vs. Battery voltage for charging and discharging cycles
f. State of charge of the battery at which the charging curve switches over to constant voltage (CV) mode from constant current (CC) mode
g. Charge cut-off level- SOC at which battery stops charging
h. Discharge cut-off level- SOC at which battery stops discharging

With the specified initial state of charge, the battery model determines the voltage of the battery from the charging curve and decides the mode of charging whether it is constant current (CC) or constant voltage (CV) mode from the SOC estimation. Based on the rate of charge and voltage of the battery, power is drawn to charge the battery. At each time instant SOC is computed. At a specified SOC of the battery, charging mode switches over from constant current charging mode to constant voltage charging mode and the charging cycle continues. Power drawn by the battery is less in constant voltage when compared to constant current mode. At a specified charge cut-off level, the battery stops charging. This is followed in DC charging stations where high power drawn from the charger may damage the health of the EV battery. The operation of the battery model is applicable during discharge cycle of the battery.

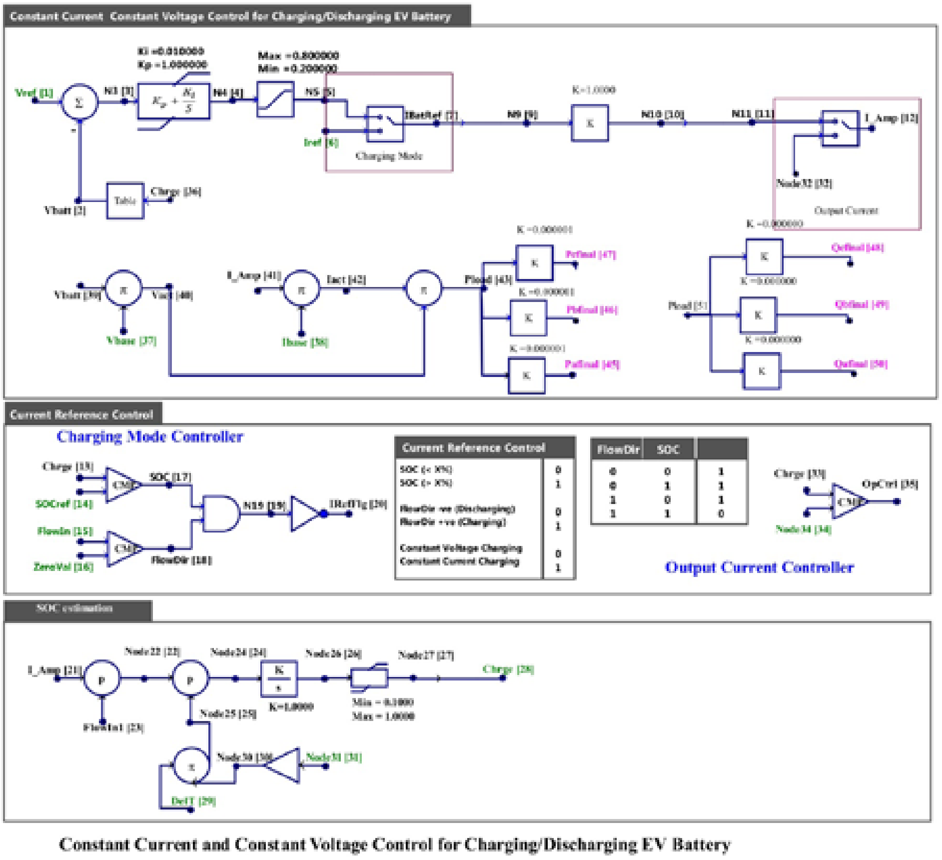


Figure 7.1.1: Battery model in used for simulation studies using MiPower software

Typical charging characteristic (SOC vs Voltage) of LFP (Lithium Ferro Phosphate) battery is shown in Figure 7.1.2. Sample graphs simulated in MiPower™ model with charging rates of 0.2C and 1C are presented in Figure 7.1.3 and Figure 4.1.4.

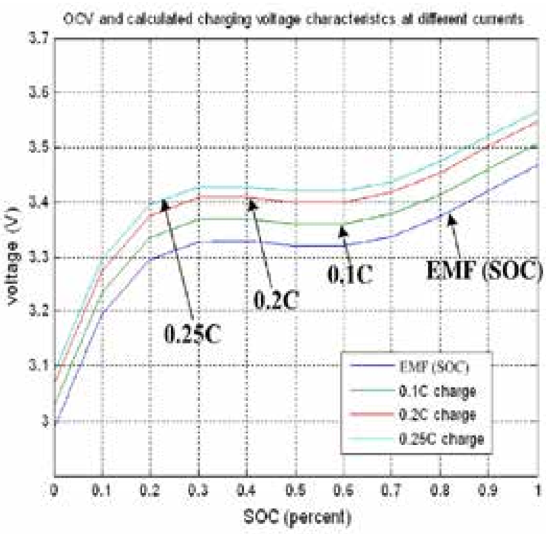


Fig. 21. Battery voltage versus SOC at different charging rates.

Figure 7.1.2: SoC Vs Voltage for various starting rate Batteries [70]

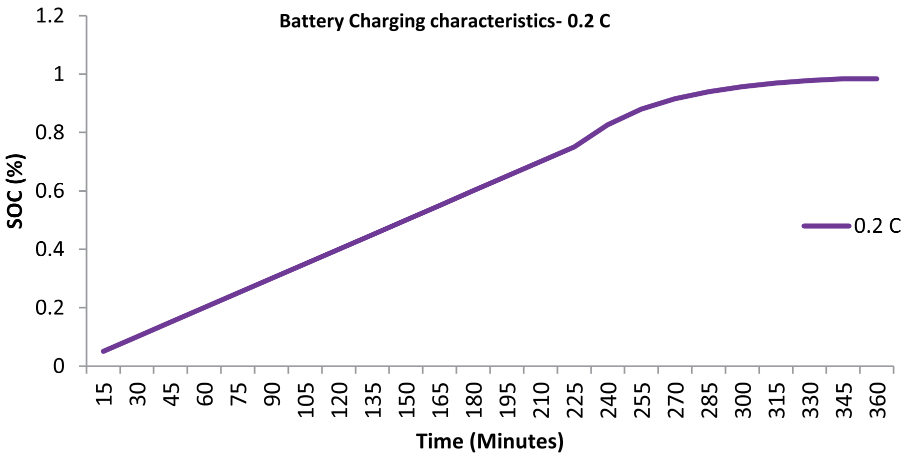


Figure 7.1.3: EV battery charging characteristics with 0.2 C

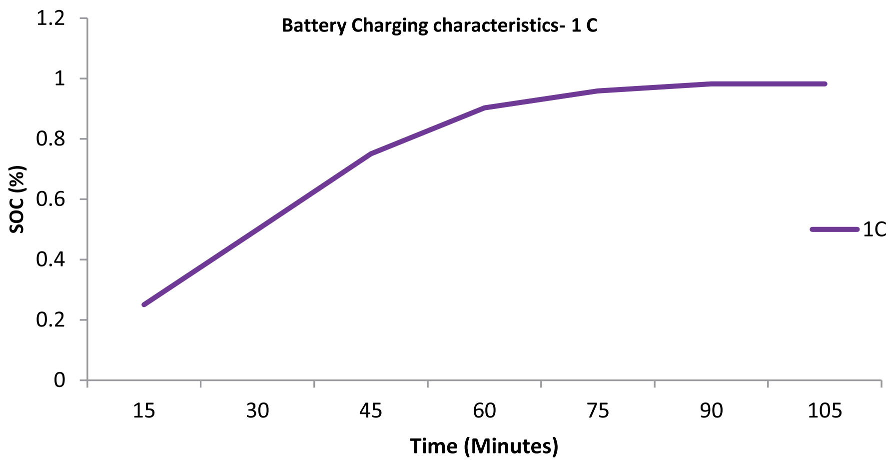


Figure 7.1.4: EV battery charging characteristics with 1 C

From the battery charging characteristics, it is observed that at 0.2 C rate of charge the EV battery charges gradually over a period of 5 hours drawing comparatively less power from the network. Hence the impact on the grid is higher when the EV battery is charged with higher rate of charge. Chargers with the rate of 1C and above are generally used in private dedicated charging locations to charge fleets, commercial charging locations etc. to charge the EV quickly.

7.2 System Modelling

EV penetration and solar rooftop penetration are considered all selected feeders and following cases are considered for years 2019, 2023 and 2030:

Base case: The distribution network of the selected feeder from 11 kV side of the feeder is modelled with loads as per selected day load profile.

Case 1: EV penetration – Penetration of EV loads on base case condition with SoC of 25%.

Case 1A: EV penetration – Penetration of EV loads on to the existing base case condition with SOC of 60%

Case 2: EV penetration and solar rooftop penetration – Penetration of EV loads on to the existing base case condition and solar rooftop generation in the feeder of following nature:

a. With typical solar generation profile

b. With varying solar generation profile

Case 3: EV penetration – Penetration of EV loads on to the existing base case condition along with one Public charger in the feeder

Case 4 : EV penetration – Penetration of EV loads on to the existing base case condition with twice the number of EV's of Case 1 (more than anticipated)

Case 5: EV penetration – Penetration of EV loads on to the existing base case condition with twice the number of EV's of Case 1 (more than anticipated) along with one public charger in the feeder

Case 6: EV penetration – Penetration of EV loads on to the existing base case condition with twice the number of EV's of Case 1 (more than anticipated) along with one public charger in the feeder and Time of Use (ToU) tariff.

Case 7: EV penetration – Penetration of EV loads on to the existing base case condition with twice the number of EV's of Case 1 (more than anticipated) along with one public charger in the feeder and grid battery storage system.

Case 8: EV penetration – Penetration of EV loads on to the existing base case condition with lower EV battery size (present battery technologies in India)

Case studies are simulated for selected feeders for future years are presented in Figure 7.2.1.

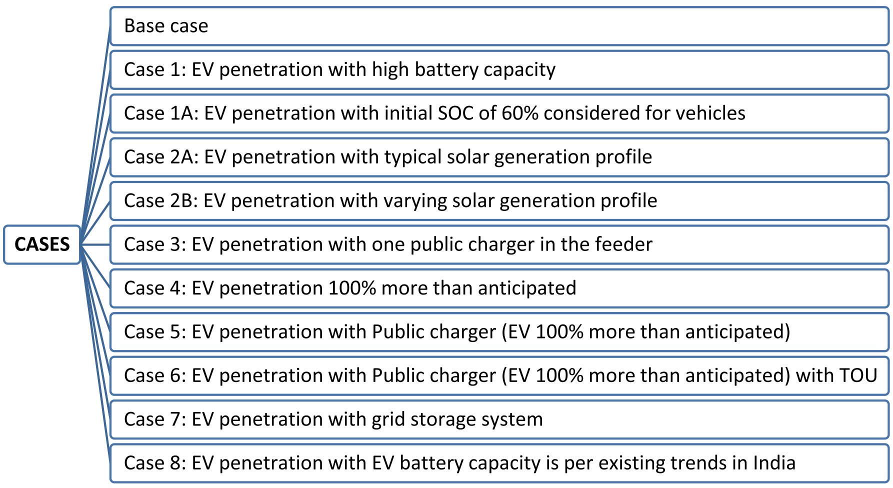


Figure 7.2.1: Case studies simulated for selected feeders for future years

The description of each case study is presented below for ready reference and the simulation results for each case for selected feeders are presented in later section.

7.2.1 Base Case

Selected feeder is modelled with corresponding DTs and poles according to their GPS locations. Typical daily load profile of the feeder under study is selected from historical data and peak load observed in the feeder for the year 2018 is considered. Sanctioned loads are modelled at each pole and scaled to match phase imbalance and DT loadings.

7.2.2 Case 1: EV Penetration

Total number of EVs projected for selected feeders are considered as furnished in methodology. Number of vehicles projected for each feeder for future years are presented in Table 7.2.1.

Table 7.2.1: Total number of EVs projected for selected feeders

Number of EVs projected for 2019			
Vehicle Type	**Janta Colony feeder**	**Arya Samaj feeder**	**MVR Sadar feeder**
2W	45	60	24
3W - PV	118	156	64
3W - CV	0	0	0
4W - PV	18	24	10
4W - CV	1	2	1
Bus	0	0	0
Total	**183**	**242**	**99**
Number of EVs projected for 2023			
Vehicle Type	**Janta Colony feeder**	**Arya Samaj feeder**	**MVR Sadar feeder**
2W	198	262	107
3W - PV	129	170	69
3W - CV	2	2	1
4W - PV	85	112	46
4W - CV	5	7	3
Bus	1	1	1
Total	**420**	**554**	**226**
Number of EVs projected for 2030			
Vehicle Type	**Janta Colony feeder**	**Arya Samaj feeder**	**MVR Sadar feeder**
2W	1,109	1,465	597
3W - PV	203	268	109
3W - CV	14	19	8
4W - PV	397	525	214
4W - CV	40	53	22
Bus	8	10	4
Total	**1,771**	**2,340**	**953**

For the feeder under study, vehicles connected at home charging, office/work charging and mall charging are considered since public charging, private dedicated charging and battery swapping stations are more likely to be installed in a commercial area. One EV charging station with number of charging points as per the MoP guidelines are simulated to charge all EVs projected under public charging location in methodology.

To simulate the worst case scenario, initial SOC of 25% is considered for the EVs since the charger draws more power in constant current mode until the SOC of the battery reaches to certain level and switches over from constant current mode to constant voltage mode where power drawl is lesser.

It is considered that for future years when the load increases in the area, the additional load coming on to the feeder is shifted to a nearby feeder or a new feeder to accommodate the additional load.

Hence the load on the selected feeder is maintained around the present peak load for the future years while performing the simulation studies.

From the historical data, CAGR energy growth of BYPL region is determined to be 4.76%. Energy consumption in BYPL region for future years is presented in Table 7.2.2. With the assumption that additional loads are transferred to another feeder in future years, the number of EVs projected under the selected feeder is shifted to the new feeder in proportion to the ratio of energy consumed by consumers. Ratio of total energy consumed in the future years to the energy consumed as per exiting system and total number of vehicles considered for each year for selected feeder are furnished in Table 7.2.3.

Table 7.2.2: Energy consumption in BYPL region for future years

Energy projections										
2019-20	2020-21	2021-22	2022-23	2023-24	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30
6925*	7254	7599	7961	8340	8736	9152	9587	10043	10521	11022

*Energy sales projected by BYPL [72]

Table 7.2.3: Total number of vehicles considered for each year for selected feeders

Feeder	Year	Total projected number of vehicles in the present feeder area	Ratio of total energy in the future years to the energy of the current year	Number of vehicles considered for simulation
Janta Colony feeder	2019	183	100%	183
	2023	420	84.65%	355
	2030	1771	63.24%	1120
Arya Samaj feeder	2019	242	100%	242
	2023	554	84.65%	469
	2030	2340	63.24%	1480
MVR Sadar feeder	2019	99	100%	99
	2023	226	84.65%	191
	2030	953	63.24%	603

7.2.3 Case 2: EV Penetration and Solar Roof Top PV Penetration

In addition to the EV penetration for the corresponding year, solar rooftop penetration is considered in this case study.

Year 2019: For the selected 3 feeders there is no existing solar rooftop generation and hence no solar penetration is considered for the year 2019.

Year 2023: MNRE has set a target for solar rooftop installation of 1100 MW in Delhi by the year 2022 [66]. Considering the BYPL share in proportion to the electrical connections, 28% of total solar rooftop is considered which amounts to 308 MW. Solar penetration considered for each feeder is given in Table 7.2.4 as per the number of residential consumers.

Table 7.2.4: Projected solar penetration for selected feeders for 2023

Feeder name	Solar roof top installed capacity				Feeder connection (%)	Solar generation in feeder (kVA) at unity PF	Feeder DT capacity (kVA)	Solar penetration (%)
	Delhi		BYPL					
	%	(MW)	%	(MW)				
Janta colony	100	1100	28	308	0.22	677.6	5840	11.60
Arya Samaj					0.29	893.2	5940	15.04
MVR Sadar					0.12	369.6	13571	2.72

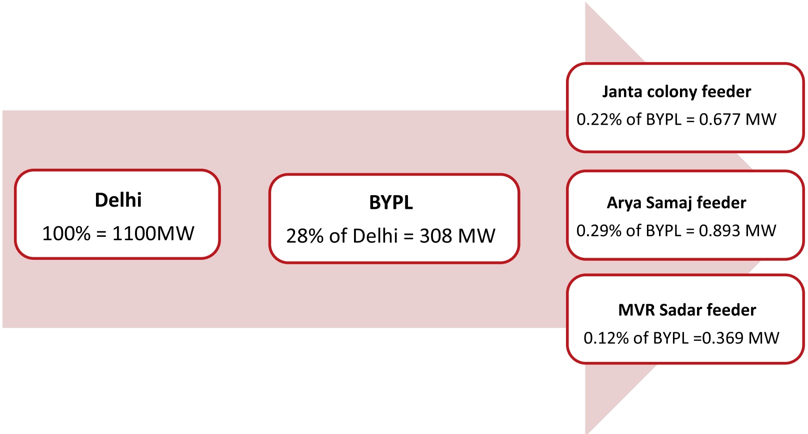


Figure 7.2.2: Solar rooftop generation considered for the year 2023

Year 2030: Total solar roof top installed capacity of 40% [67] of DT capacity is considered in the selected feeders for reference purpose. Solar penetration considered on each feeder for the year 2030 is shown in Table 7.2.5.

Table 7.2.5: Projected solar penetration considered on each feeder for the year 2030

Feeder name	Feeder DT capacity (kW)	Solar penetration (%)	Solar installed capacity (MW)
Janta colony	5548	40	2.21
Arya Samaj	5643	40	2.25
MVR Sadar	12892	40*	0.54

Sadar feeder consists mainly of housing societies and penetration of 40% solar generation is unrealistic considering the space constraints. Hence 40% solar penetration is considered for only for few DTs. 3 DTs out of 23 DTs are non-housing DTs of capacities 2x400kVA + 1x630 kVA=1430 kVA. Considering 0.95 PF, 1430*0.95*40%= **543kW*

7.2.3.1 Case 2A: EV Penetration and Typical Solar Rooftop Generation Profile

Solar rooftop generation of IHBAS feeder in BYPL region is taken as reference for solar rooftop generation. A typical solar generation profile is considered in the selected feeders. Based on the historical solar rooftop data, it is observed that 90% of the solar installed capacity will be connected to the grid at its maximum power generation and same is considered in the simulation studies. Typical solar generation profile considered for simulation studies is shown in Figure 7.2.3.

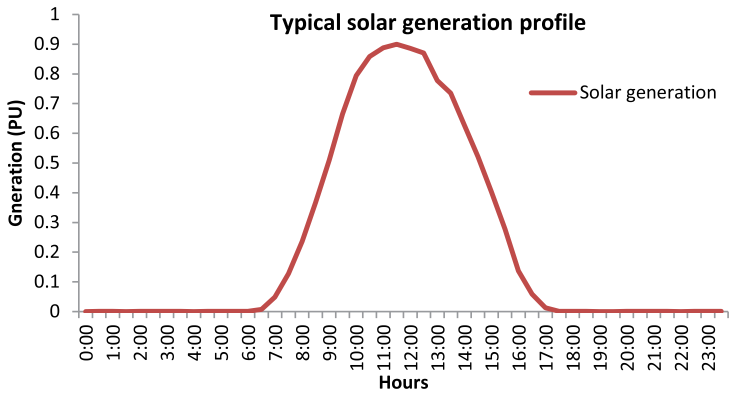


Figure 7.2.3: Typical solar generation profile

7.2.3.2 Case 2B: EV Penetration and Variable Solar Rooftop Profile

Typical varying solar generation profile considered from historical data of IHBAS feeder is considered for simulation studies and same is shown in Figure 7.2.4.

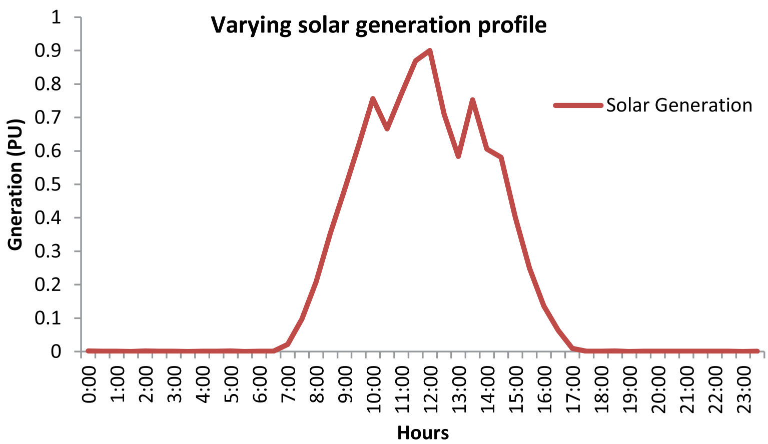


Figure 7.2.4: Solar generation profile with variation

08

Impact of EVs on Selected Feeders in BYPL

5.1 Arya Samaj Feeder

Arya samaj, 11 kV feeder emanates from 33/11 kV Shastri Park substation and consists of 7 distribution transformers in 4 different locations. Arya samaj feeder consists of 3767 connections in total, which contributes to 0.22% of total BYPL connections. Arya samaj feeder network is presented in Figure 5.4.2. Total number of EVs projected for Arya samaj feeder for future years considered from Table 7.2.3 and same is shown in

Figure 8.1.1.

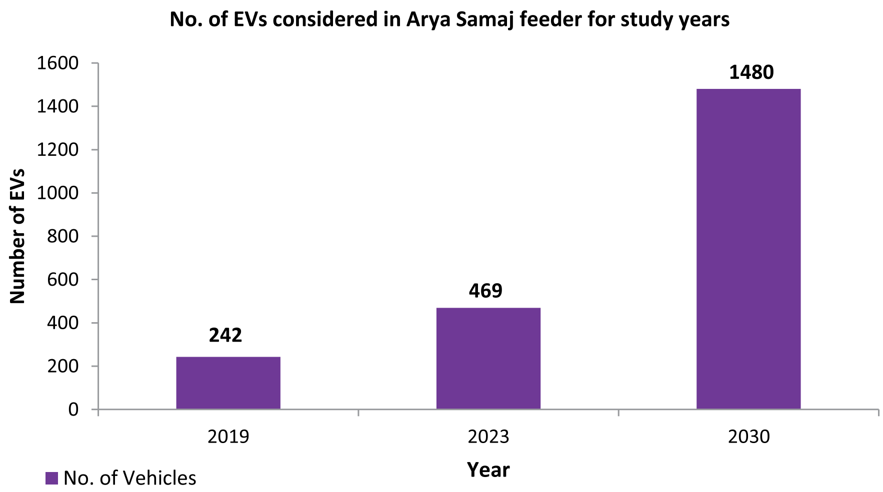


Figure 8.1.1: Total number of EVs projected for Arya samaj feeder for future years

8.1.1 Base Case

Arya samaj feeder network is modelled with the existing loads as per the selected load profile. Typical daily load profile for Arya samaj feeder for the month of June is considered since Delhi peak and BYPL peak were observed in the month of June. Feeder peak demand of 4.32 MW is observed for Arya samaj feeder in 2018 and the same is considered with the selected load profile as shown in Figure 8.1.2.

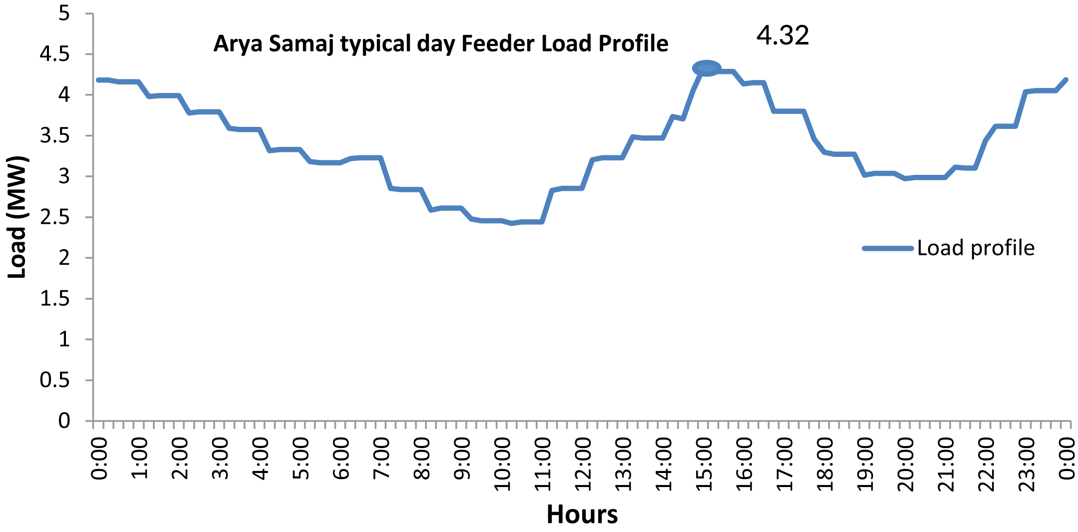


Figure 8.1.2: Arya samaj feeder-Typical day load profile

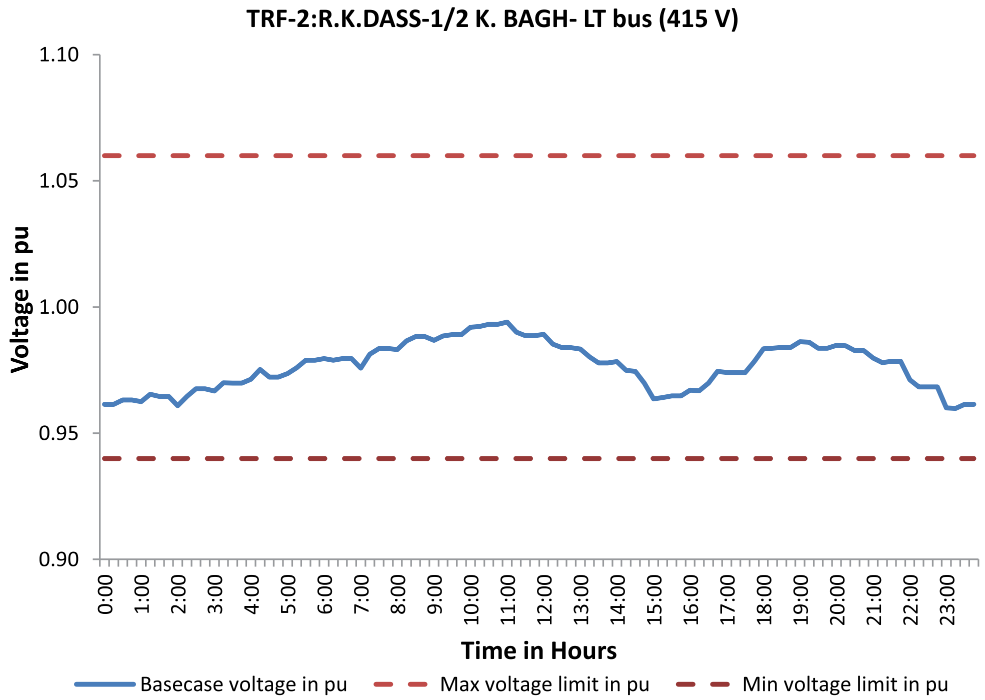


Figure 8.1.3: Arya samaj feeder- Simulated DT-LT voltage profile

Figure 8.1.3 shows voltage profile at LT side of tail end DT (Farthest from grid point). Considering the voltage limits of ±6% on low tension as per DERC Distribution Code, the voltage is within the acceptable limits.

Sanctioned loads are modelled at each pole and scaled to match phase imbalance and DT loading for every 15 minutes interval as per the available feeder loading. Transformer loading in base case is presented in Table 8.1.1.

Table 8.1.1: Arya samaj transformer loading in base case

Transformer name	Transformer Capacity (MVA)	Transformer loading at feeder peak (MW)	Simulated results of transformer loading (MW)	Error %
TRF-1:ARYA SAMAJ ROAD NALA	0.99	0.564	0.572	1.37%
TRF-2:ARYA SAMAJ ROAD NALA	0.99	0.757	0.784	3.58%
TRF-1:R.K.DASS-1 K.BAGH	0.99	0.864	0.899	4.03%
TRF-2:R.K.DASS-1 K.BAGH	0.99	0.885	0.902	1.92%
TRF-1:73 REGAR PURA	0.99	-	-	-
TRF-1:R.K.DASS-1/2 K.BAGH	0.99	0.609	0.622	2.19%
TRF-2:R.K.DASS-1/2 K. BAGH	0.99	0.645	0.658	2.07%

8.1.2 Simulation Studies for the Year 2030

Considering the advancement in battery technology and current EV trends in European countries, for the year 2030, higher battery sizes of EVs are considered. With higher EV battery capacity it is natural that the ranges of the EVs are higher which means frequency of charging the EV is lesser. Considering the fact that the average daily distance commuted by all the vehicle categories will be same in the future, total number of charges per vehicle per year with 25% initial SOC is calculated. Higher battery capacities are considered as per the current trends in European countries and their corresponding number of charges per year is presented in Table 8.1.2.

Table 8.1.2: EV Battery capacities considered for year 2030

Vehicle Category	Battery Capacity (kWh)	No. of charges per year per vehicle
2W	4	65
3W - PV	7	487
3W - CV	9	389
4W - PV	80	48
4W - CV	80	292
Bus	250	389

Cases considered for Arya samaj feeder for year 2030 is presented in Figure 8.1.4.

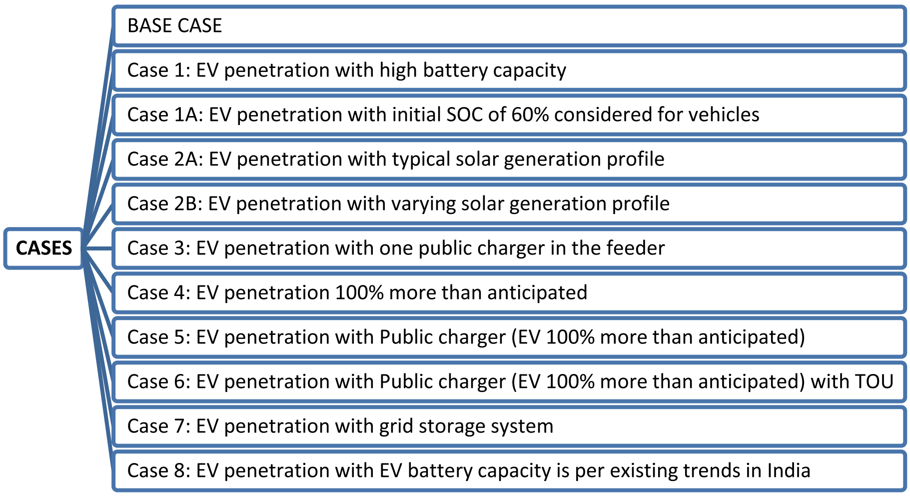


Figure 8.1.4: Cases considered for Arya samaj feeder for year 2030

Table 8.1.3: Description for cases considered for Arya samaj feeder for year 2030

Case description	EV-Initial SOC 25%	EV-Initial SOC 60%	EV-More than anticipated (Additional)	EV-Lower battery size	Solar profile A	Solar profile B	Public Charger	TOU	Grid storage
Case-1	✓	×	×	×	×	×	×	×	×
Case-1A	×	✓	×	×	×	×	×	×	×
Case-2A	✓	×	×	×	✓	×	×	×	×
Case-2B	✓	×	×	×	×	✓	×	×	×
Case-3	✓	×	×	×	×	×	✓	×	×
Case-4	✓	×	✓	×	×	×	×	×	×
Case-5	✓	×	✓	×	×	×	✓	×	×
Case-6	✓	×	✓	×	✓	×	✓	✓	×
Case-7	✓	×	✓	×	✓	×	✓	×	✓
Case-8	×	×	×	✓	×	×	×	×	×

8.1.2.1 Case 1: EV Penetration

Total EVs and total charges considered for the year 2030 are presented in Figure 8.1.5. Distribution of charging of each vehicle category at different charging locations is furnished from Figure 8.1.6 to Figure 8.1.8.

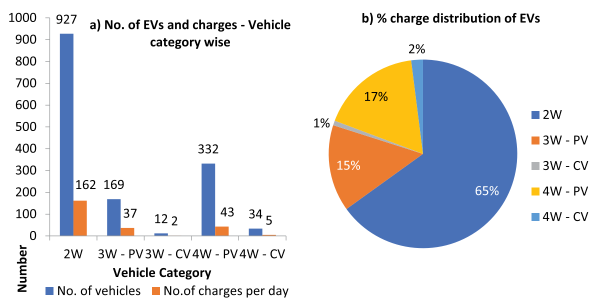


Figure 8.1.5: a) No. of EVs and charges - Vehicle category wise b) % charge distribution of EVs

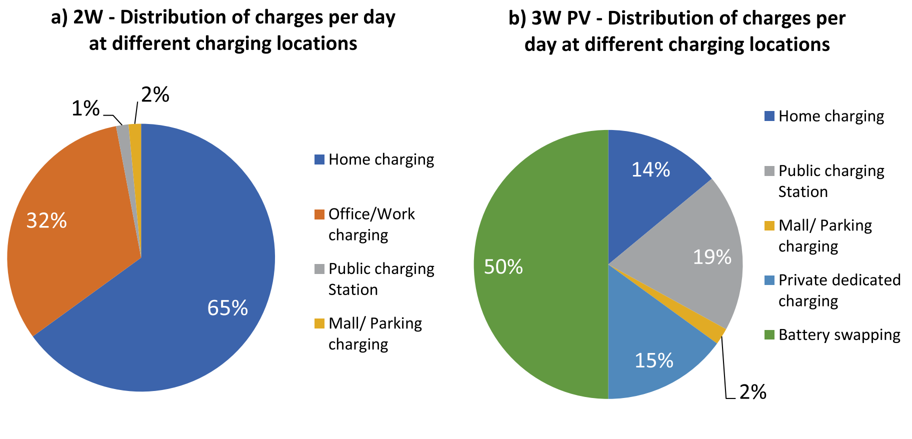


Figure 8.1.6: a) 2W – location wise charge distribution b) 3W PV – location wise charge distribution

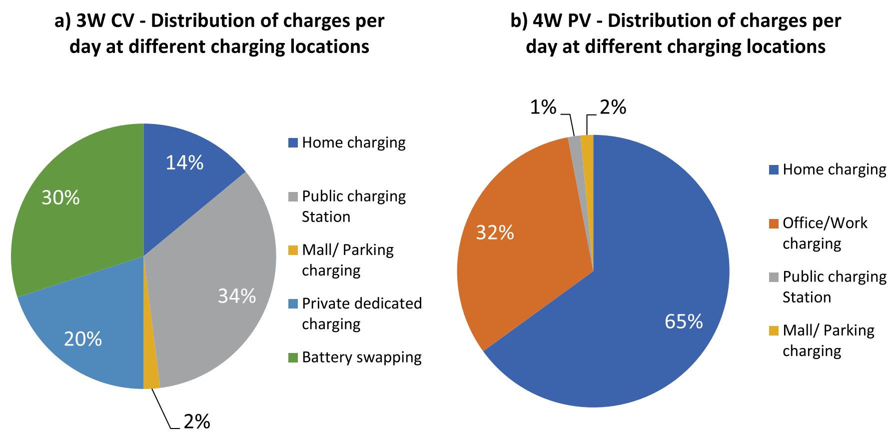


Figure 8.1.7: a) 3W CV – location wise charge distribution b) 4W PV – location wise charge distribution

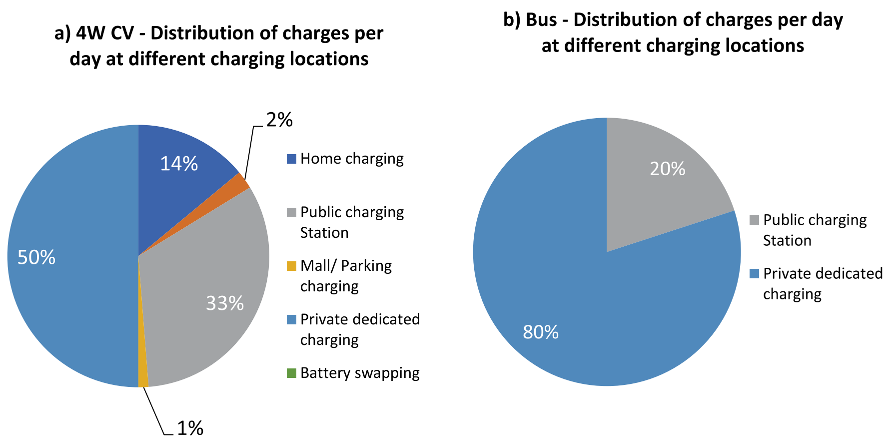


Figure 8.1.8: a) 4W CV – location wise charge distribution b) Bus – location wise charge distribution

Total number of EV charges per day considered in Arya samaj feeder for 2030 is furnished in Table 8.1.4.

Table 8.1.4: Total EV charges per day considered in Arya samaj feeder for 2030

Vehicle category	Home charging	Office/Work charging	Mall/ Parking charging
2W	107	53	2
3W - PV	32	-	5
3W - CV	2	-	-
4W - PV	28	14	1
4W - CV	4	1	-
Bus	-	-	-

Total number of EV charges considered per day for different vehicle categories are distributed throughout the day in different time slots, from TS1 to TS24. EVs are plugged in at different poles under different DTs randomly. The random distribution has been selected as EV penetration under each DT will not follow uniform distribution in the future times. Random distribution of EVs for each DT in Arya samaj feeder throughout the day for different time slots is presented in Table 8.1.5.

Table 8.1.5: Random distribution of EVs for each DT in Arya samaj for 2030

Random distribution of EVs under each DT		
Name of the DT	**No. of EVs plugged in a day**	**Cumulative battery capacity (kWh)**
TRF-1:ARYA SAMAJ ROAD NALA	50	1176
TRF-2:ARYA SAMAJ ROAD NALA	42	740
TRF-1:R.K.DASS-1 K.BAGH	32	822
TRF-2:R.K.DASS-1 K.BAGH	40	655
TRF-1:R.K.DASS-1/2 K.BAGH	34	763
TRF-2:R.K.DASS-1/2 K. BAGH	49	839
Total		**4995**

Case study is executed for a period of 24 hours with the selected load profile including the EV loads plugged in at different point of times in a day. Arya samaj 11 kV feeder load profile with EV loads is presented in Figure 8.1.9.

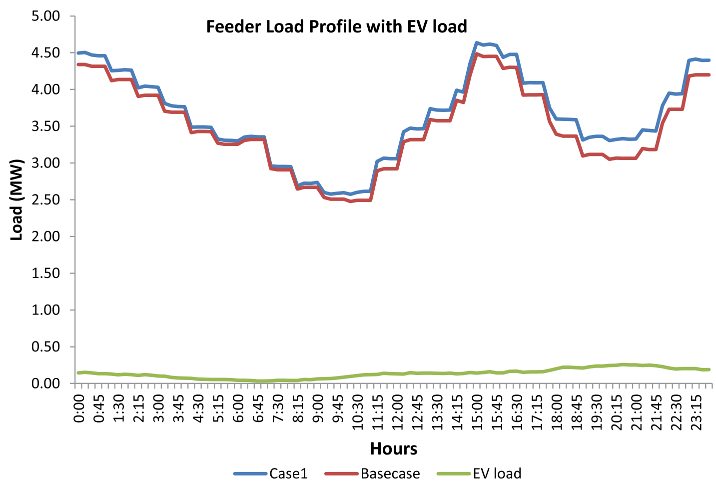


Figure 8.1.9: Arya samaj feeder load profile with EV loads

Peak load of the feeder is 4.63 MW at 15:00 hours and corresponding EV load of 140.39 kW is observed. EV peak load of 257.02 kW is observed at 20:30 hours and corresponding feeder loading is 2.99MW (8.6% of feeder load).

Total energy consumed by feeder is 86.97 MWh with the contribution of 3.24 MWh by the connected EV loads, which corresponds to 3.73% of feeder daily energy consumption. Energy loss is 2.99%, 2.6 MWh with EV load and Summary of the observations are presented in Table 8.1.6.

Table 8.1.6: Arya samaj - 2030 observations for Case 1

Feeder peak		
Feeder peak load (MW)	4.63	
Time	15:00	
EV load (kW)	140.39	
Maximum EV load		
EV peak (kW)	257.02	
Time	20:30	
Feeder load (MW)	2.99	
EV peak % of feeder load	8.60%	
Energy consumption		
Energy consumption by feeder (MWh)	86.97	
Energy consumption by EV (MWh)	3.24	
% Energy consumption by EV	3.73%	
Energy supplied		
By Grid (MWh)	86.97	
By Solar PV (MWh)	-	
11kV feeder loss		
Unit	(MWh)	(%)
Case 1 (MWh)	2.60	2.99%

It is observed from Table 8.1.6 that the feeder load profile changes with the addition of EVs and adds to the existing loading in the system. 11kV feeder loading current (A) with and without EVs in the system is presented in Figure 8.1.10.

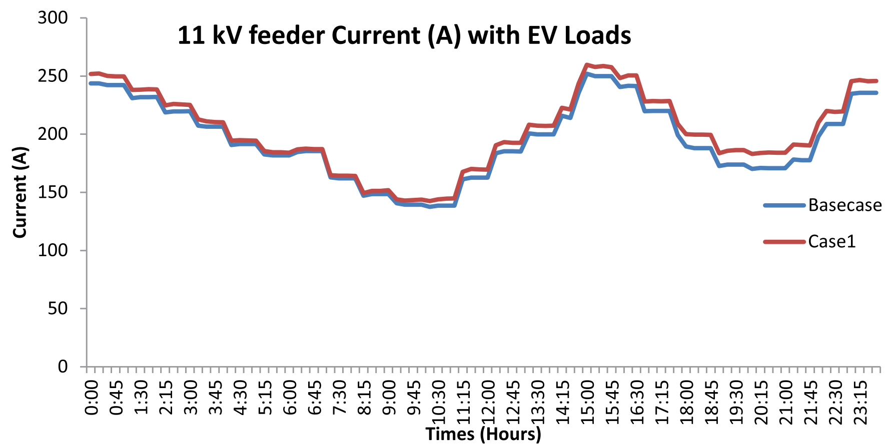


Figure 8.1.10: 11 kV feeder current profile with EV loads

Arya samaj consists of 6 distribution transformers and the loading of each transformer throughout the day with EV load in the feeder is presented from Figure 8.1.11 to Figure 8.1.13.

Nomenclatures for transformers in Arya Samaj feeder are presented in Table 8.1.7. From the simulation results, it is observed that high EV penetration is there during morning and evening periods. Impact of loading on each DT varies as per the charging behaviour and connected EVS under DTs which follows random distribution.

It can also be noted that, DT: RKD1K2_990KVA and DT: RKD2KL2_990KVA are already overloaded in the base case with loading of more than 100% for certain period of time. Hence these two transformers can be considered for upgradation.

Table 8.1.7: Transformer nomenclature

Transformer name	Nomenclature
TRF-1:ARYA SAMAJ ROAD NALA	DT: ASRN1_990KVA
TRF-2:ARYA SAMAJ ROAD NALA	DT: ASRN2_990KVA
TRF-1:R.K.DASS-1 K.BAGH	DT: RKD1K1_990KVA
TRF-2:R.K.DASS-1 K.BAGH	DT: RKD1K2_990KVA
TRF-1:R.K.DASS-1/2 K.BAGH	DT: RKD2KL1_990KVA
TRF-2:R.K.DASS-1/2 K. BAGH	DT: RKD2KL2_990KVA

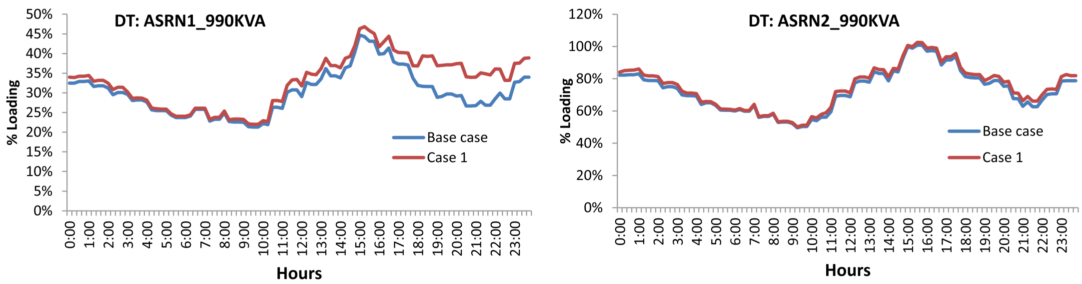


Figure 8.1.11: Transformer % loading of ASRN_HT1_990kVA and ASRN_HT2_990kVA

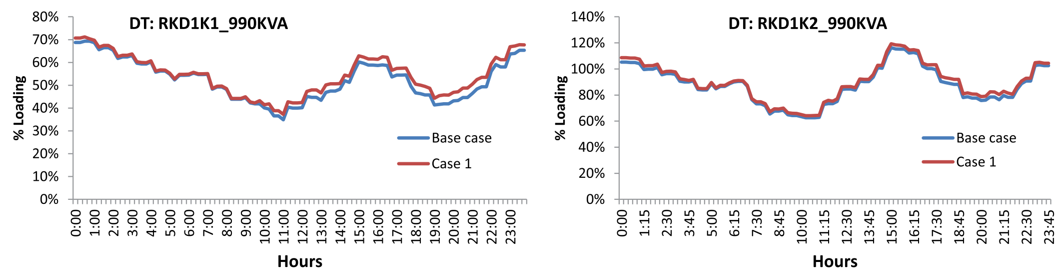


Figure 8.1.12: Transformer % loading of RKD1KHT1_990kVA and RKD1KHT2_990kVA

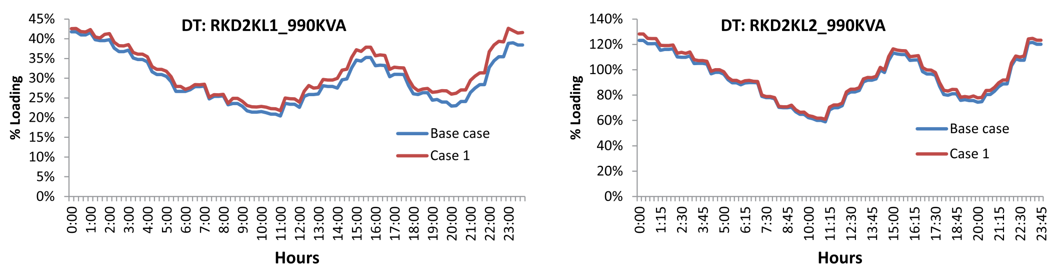


Figure 8.1.13: Transformer % loading of RKD2KHT1_990kVA and RKD2KHT2_990kVA

8.1.2.2 Case 1A: EV Penetration with Initial SoC of 60%

To understand the impact of EV charging with higher SoC, this case is executed. EV when plugged in to the system with higher SoC, the power drawl is lesser and frequency of charging the EV is higher. Total charges per vehicle per year with 60% initial SOC is furnished in Table 8.1.8.

Table 8.1.8: Total EV charges per vehicle per year with 60% initial SOC

Vehicle category	Initial SOC	Range	Average km	Range left	Plug-in after X km	Annual km	Charges per year
2W	60	150	20	90	60	7300	122
3W - PV	60	100	100	60	40	36500	913
3W - CV	60	100	80	60	40	29200	730
4W - PV	60	350	34.3	210	140	12520	89
4W - CV	60	350	210	210	140	76650	548
Bus	60	250	200	150	100	73000	730

Arya samaj feeder network with EV penetration (with 60% initial SOC) is considered and simulated for a period of 24 hours. Arya samaj, 11 kV feeder load profile with EV loads is presented in Figure 8.1.14.

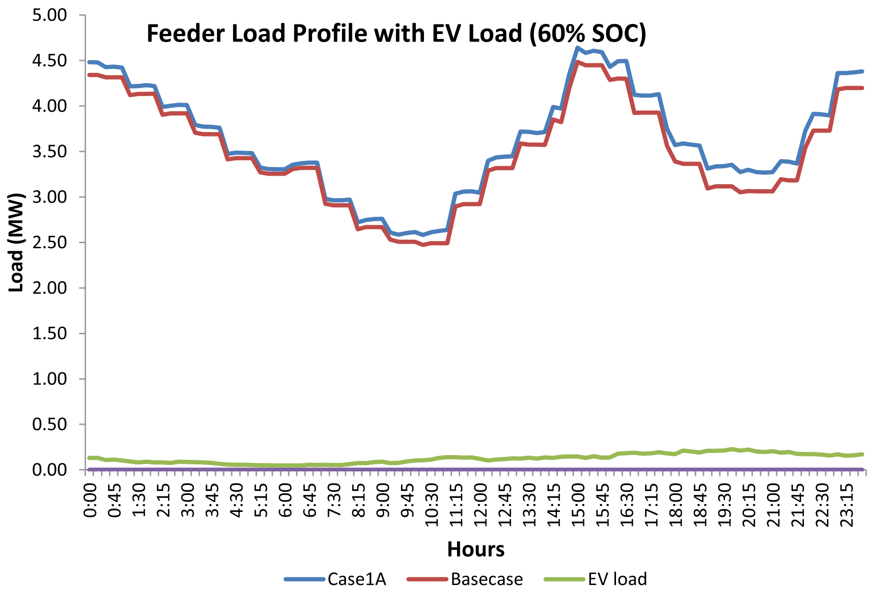


Figure 8.1.14: Arya samaj feeder load profile with EV loads (with 60% initial SOC)

Peak load of the feeder is 4.64 MW at 15:00 hours and corresponding EV load of 147.59 kW is observed. EV peak load of 226.85 kW is observed at 19:45 hours and corresponding feeder loading is 3.04MW (7.47% of feeder load).

Total energy consumed by feeder is 86.73 MWh with the contribution of 3.01 MWh by the connected EV loads, which corresponds to 3.47% of feeder daily energy consumption. Energy loss is 3%, 2.6 MWh with EV load and summary of the observations are presented in Table 8.1.9.

Table 8.1.9: Arya samaj 2030 observations for Case 1A

Feeder peak		
Feeder peak load (MW)	4.64	
Time	15:00	
EV load (kW)	147.59	
Maximum EV load		
EV peak (kW)	226.85	
Time	19:45	
Feeder load (MW)	3.04	
EV peak % of feeder load	7.47%	
Energy consumption		
Energy consumption by feeder (MWh)	86.73	
Energy consumption by EV (MWh)	3.01	
% Energy consumption by EV	3.47%	
Energy supplied		
By Grid (MWh)	86.73	
By Solar PV (MWh)	-	
11kV feeder loss		
Unit	(MWh)	(%)
Case 1A (MWh)	2.60	3.00%

It is observed from this case that when EVs are plugged in to the grid at higher frequencies with higher SOC, the impact is less on the grid. EV peak of around 257 kW is observed with EVs plugged in with 25% initial SOC and around 226 kW when plugged in with 60% initial SOC.

8.1.2.3 Case 2A: EV Penetration and Typical Solar Rooftop Generation Profile

Arya samaj feeder network with EV penetration and typical solar generation is considered and simulated for a period of 24 hours. Total installed capacity of solar rooftop generation of 2.37 MW is considered. Arya samaj, 11 kV feeder load profile with EV loads and solar rooftop generation is presented in Figure 8.1.15.

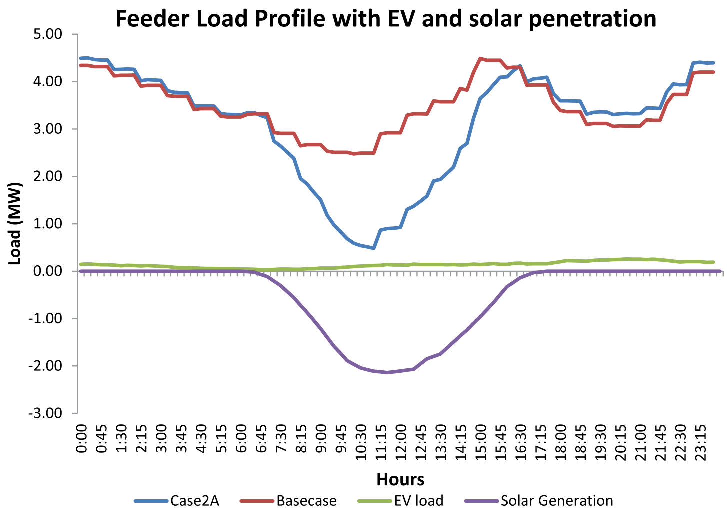


Figure 8.1.15: Arya samaj feeder load profile with EV loads and solar penetration

It is observed from that energy drawn from the grid reduces significantly with solar generation in the feeder.

Peak load of the feeder is 4.5 MW at 00:15 hours and corresponding EV load of 152.71 kW is observed. EV peak load of 257.02 kW is observed at 20:30 hours and corresponding feeder loading is 2.99MW (8.6% of feeder load).

Total energy consumed by feeder is 86.73 MWh with the contribution of 3.24 MWh by the connected EV loads, which corresponds to 3.74% of feeder daily energy consumption. Energy loss is 2.73%, 2.37 MWh with EV load and summary of the observations are presented in Table 8.1.10.

Table 8.1.10: Arya samaj 2030 observations for Case 2A

Feeder peak		
Feeder peak load (MW)	4.50	
Time	0:15	
EV load (kW)	152.71	
Maximum EV load		
EV peak (kW)	257.02	
Time	20:30	
Feeder load (MW)	2.99	
EV peak % of feeder load	8.60%	
Energy consumption		
Energy consumption by feeder (MWh)	86.73	
Energy consumption by EV (MWh)	3.24	
% Energy consumption by EV	3.74%	
Energy supplied		
By Grid (MWh)	73.98	
By Solar PV (MWh)	12.75	
11kV feeder loss		
Unit	(MWh)	(%)
Case 2A (MWh)	2.366	2.73%

11kV feeder loading (A) with EV load and typical solar generation in the system is presented in Figure 8.1.16.

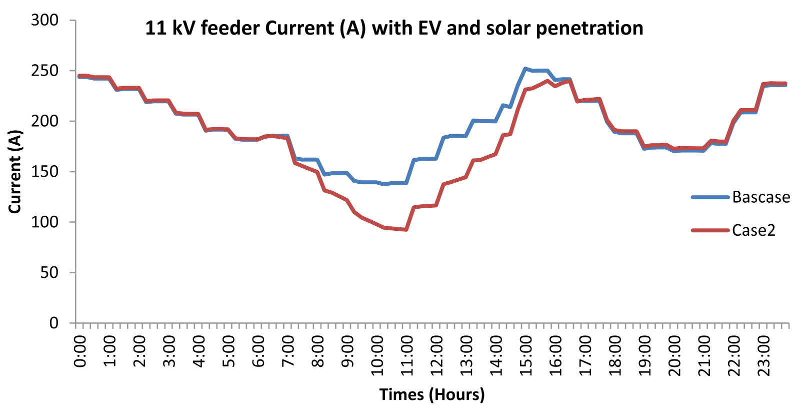


Figure 8.1.16: 11 kV feeder current profile with EV loads and typical solar generation profile

Percentage loading of distribution transformers with EV loads and solar generation in the feeder are presented from Figure 8.1.17 to Figure 8.1.19.

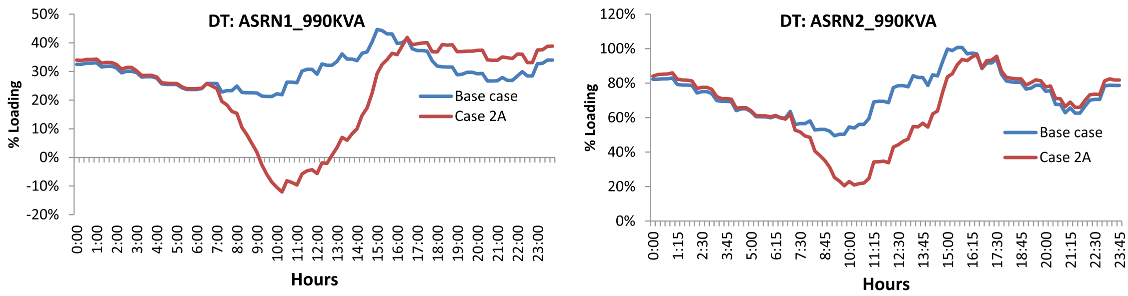


Figure 8.1.17: Transformer % loading of ASRN1_990KVA and ASRN2_990KVA

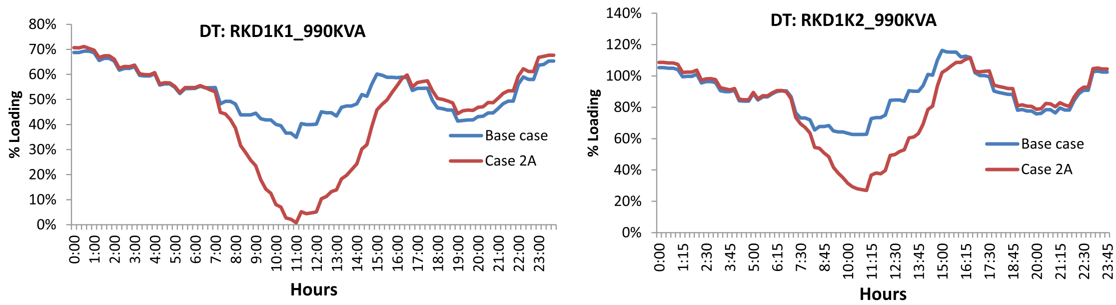


Figure 8.1.18: Transformer % loading of RKD2K1_990KVA and RKD2K2_990KVA

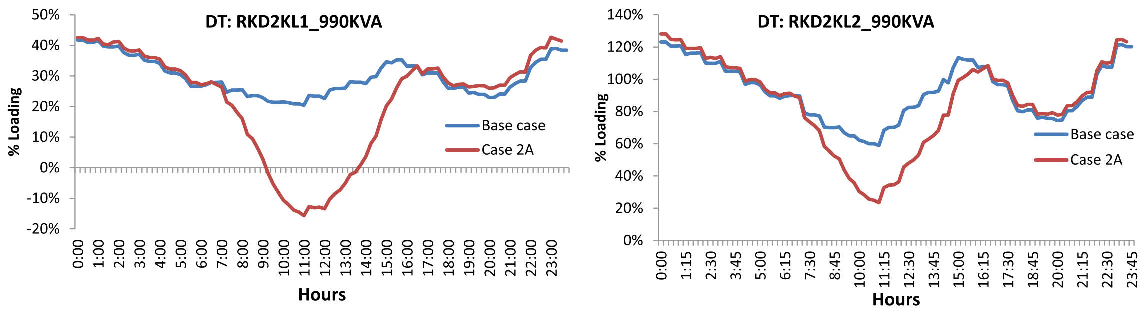


Figure 8.1.19: Transformer % loading of RKD2KL2_990KVA and RKD2KL2_990KVA

From the simulation studies, it is observed that the impact of EV charging during PV generation is minimum or nil. Feeder can take up more EV charging scenarios during PV generation. The additional EV load that can be taken up with PV generation and the change time slots to PV generation time by means of Time of Usage (ToU) tariff are presented in case 6 of this section.

It can be noted that from figures Figure 8.1.17 and Figure 8.1.19 that there is a reverse power flow in the transformer during peak solar time.

It is also seen from Figure 8.1.18 that the loading of the DT becomes negative when PV generation reaches to maximum. However, considering the Arya Samaj 11 kV feeder, when PV generation is maximum 2.14 MW (90% of 2.37 MW) and corresponding feeder load is around 2.99 MW and no reverse power flow is observed due to diversity of PV generation thorough out the feeder. Similar diversity may be observed on other 11 kV feeders. Hence in case, DISCOM want to control the reverse power flow at 33/11 kV grid transformer, the maximum solar PV penetration can be limited to minimum loading of grid transformer with proper configuration of protection coordination under grid transformer. This will make sure no changes in protection settings above grid transformer. This allows more PV penetration above 40% of DT capacity under each DT and maintains no reverse power flows at grid transformer. In other way, by enhancing protection settings and maintain harmonics within the limit, PV roof top penetration can be increased further. DISCOM can take a call on case-to-case basis.

Note on protection settings due to high roof-top solar generation:

When a PV installation is located far away from a substation with loads between them, the power can flow in opposite directions from the two sources toward the loads. Power flow can change direction in distribution power systems when the PV generation is larger than local consumption. This reverse power can cause protection and power quality issues. Backfeeding occurs when PV generation on a feeder exceeds feeder demand. This can occur when PV penetration is high during low-load periods. As the penetration level increases, backfeeding occurs more often and even at a higher loading level.

In general, directional overcurrent relays (DOCRs) are the best solution to avoid the sympathetic trippings in multi loop systems. But in case of a large penetration of the RES, because of their intermittent nature, fault levels on the network will change with respect to the level of RES penetration. DOCR with fixed time dial setting (TDS) and plug multiplier setting (PS) will not protect the feeder from a large penetration of the RES. Particularly, the change in fault current primarily depends on the type, rating (penetration) and location of the RES integration in the network. The change in fault level seen by the relays will result in the under reach operation of the relays.

The following protection issues will arise in the distribution system with large penetration DERs (Distributed Energy Resources):

1. False Tripping or Sympathetic Tripping
2. Blinding operation of the relay
3. Islanding Problems
4. Loss of Coordination
5. Auto Recloser Problems

Hence the traditional protection schemes were not suitable and new protection schemes for distribution systems when high DERs penetrates into the system. Various schemes proposed in the literature to limit the impacts on distribution grid due to high DERs are presented below for quick reference.

1. Point of Common Coupling (PCC) Voltage Based Protection Scheme
2. Distance Protection on Distribution System
3. Modifying Protection Scheme
4. Limiting the RES Capacity
5. Using Fault Current Limiters

The details of the various protection issues with large penetration of DERs are presented in [73].

8.1.2.4 Case 2B: EV Penetration and Variable Solar Rooftop Profile

Arya samaj feeder network with EV penetration and varying solar generation is considered and is simulated for a period of 24 hours. Total installed capacity of solar rooftop generation of 2.37 MW is considered. Arya samaj 11 kV feeder load profile with EV loads and varying solar roof top generation is presented in Figure 8.1.20.

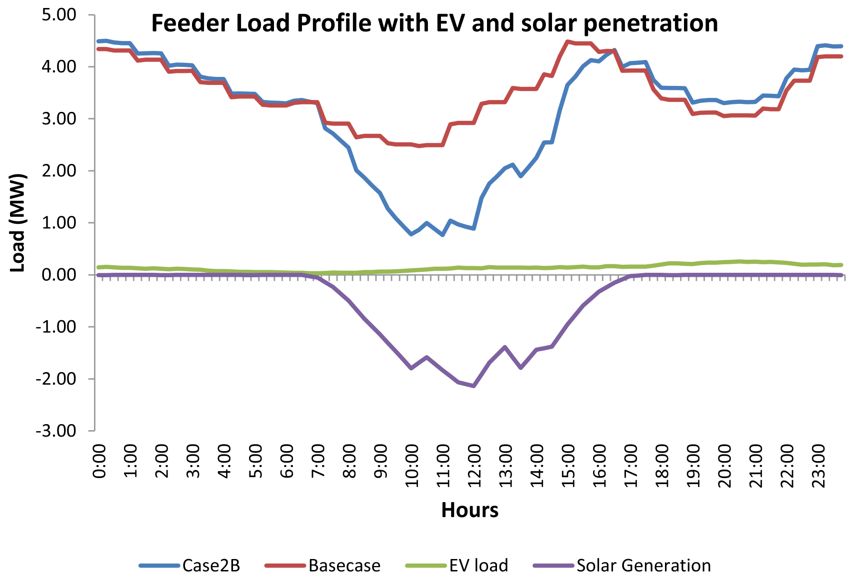


Figure 8.1.20: Arya samaj feeder load profile with EV loads and solar penetration

It is observed from Figure 8.1.20 that energy drawn from the grid reduces significantly with solar generation in the feeder. The pattern of power drawl from the grid reflects the rooftop solar generation pattern.

Peak load of the feeder is 4.5 MW at 00:15 hours and corresponding EV load of 152.71 kW is observed. EV peak load of 257.02 kW is observed at 20:30 hours and corresponding feeder loading is 2.99MW (8.6% of feeder load).

Total energy consumed by feeder is 86.74 MWh with the contribution of 3.24 MWh by the connected EV loads, which corresponds to 3.74% of feeder daily energy consumption. Energy loss is 2.74%, 2.38 MWh with EV load and summary of the observations are presented in Table 8.1.11.

Table 8.1.11: Arya samaj 2030 observations for Case 2B

Feeder peak	
Feeder peak load (MW)	4.50
Time	0:15
EV load (kW)	152.71
Maximum EV load	
EV peak (kW)	257.02
Time	20:30
Feeder load (MW)	2.99
EV peak % of feeder load	8.60%
Energy consumption	
Energy consumption by feeder (MWh)	86.74
Energy consumption by EV (MWh)	3.24
% Energy consumption by EV	3.74%

Energy supplied		
By Grid (MWh)	75.03	
By Solar PV (MWh)	11.71	
11kV feeder loss		
Unit	(MWh)	(%)
Case 2A (MWh)	2.377	2.74%

11kV feeder loading (A) with EV load and varying solar generation in the system is presented in Figure 8.1.21.

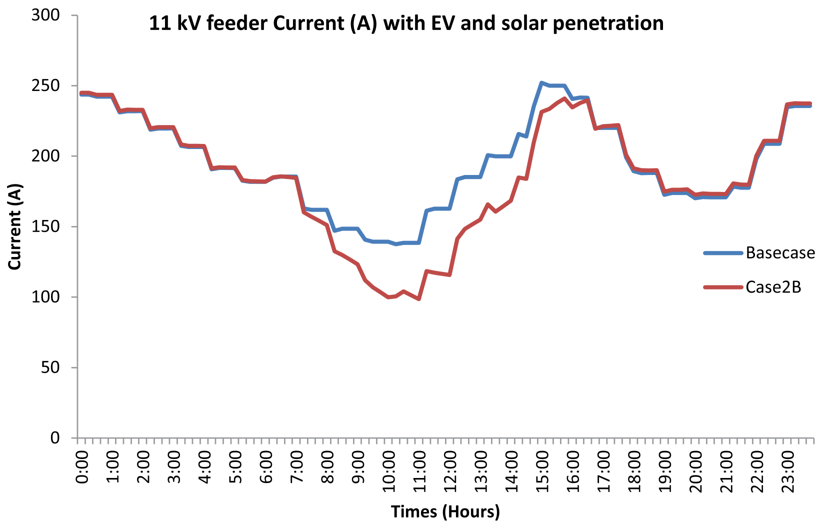


Figure 8.1.21: 11 kV feeder current profile with EV loads and varying solar generation profile

Percentage loading of the distribution transformers is similar to case2A and hence not included in the report.

8.1.2.5 Case 3: EV Penetration with Public Charging Station

According to Ministry of Power (MOP) regulations [71], a public charging station shall have one or more electric kiosks/boards with installation of following:

a. Fast charger – CCS connector (min 50 kW), CHAdeMO (min 50 kW), Type 2 AC (min 22 kW)

b. Slow/Moderate charger – Bharat DC-001 connector (15 kW) and Bharat AC-001 (10 kW)

Considering above charging point capacity, the number of charging points at public charging station are increased considerably to accommodate the EVs projected in the methodology.

It is considered that for future years when the load increases in the area, the additional load coming on to the feeder is shifted to a nearby feeder or a new feeder is commissioned to accommodate the additional load. Therefore the number of EVs projected under the selected feeder is shifted to the new feeder in proportion to the ratio of energy consumed by consumers.

Arya samaj feeder network with public charging station is presented in Figure 8.1.22. As there are no voltage issues are observed in the feeder due to load and EV loads, Public charger is considered at the middle of the feeder. In case of voltage violations in the feeder, the optimal location of public charger is at the starting of 11 kV feeder. In this case, public charging station is considered with 2x400kVA, 11/0.433 kV transformers to cater the EV load.

In addition to EV's distributed across Arya samaj as furnished in Table 8.1.5, vehicles distribution throughout the day for DT in public charging station is given in Table 8.1.12

Table 8.1.12: Random distribution of EVs under Public Charger DT in Arya Samaj for 2030

Name of the DT	No of EV's	Cumulative battery capacity (kWh)
DT-Public Charging	96	2167

11 kV feeder load profile with regular EV loads and a public charger is presented in Figure 8.1.23. No solar PV generation is considered for this case.

Figure 8.1.22: Arya Samaj distribution network with 1 public charging station

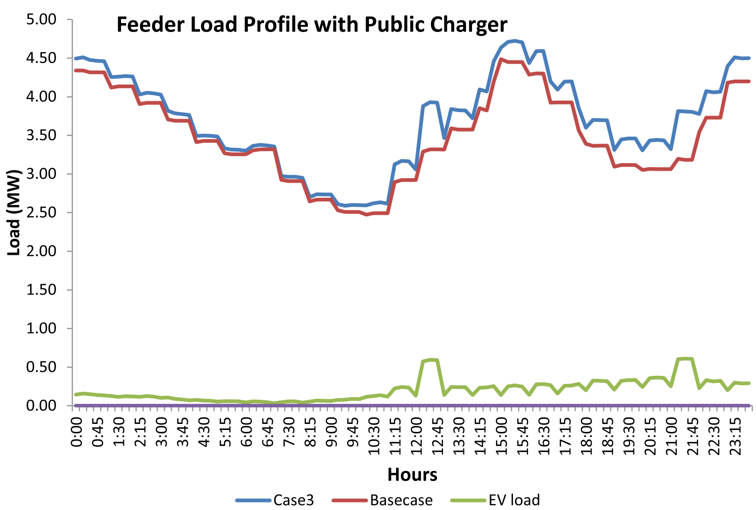


Figure 8.1.23: Arya samaj feeder load profile with EV loads and a public charger

Peak load of the feeder is 4.72 MW at 15:30 hours and corresponding EV load of 264.12 kW is observed. EV peak load of 611.5 kW is observed at 21:30 hours and corresponding feeder loading is 3.1MW (19.72% of feeder load).

Total energy consumed by feeder is 88.55 MWh with the contribution of 4.8 MWh by the connected EV loads, which corresponds to 5.42% of feeder daily energy consumption. Energy loss is 2.97%, 2.63 MWh with EV load and summary of the observations are presented in Table 8.1.13.

Table 8.1.13: Arya samaj 2030 observations for Case 3

Feeder peak		
Feeder peak load (MW)	4.72	
Time	15:30	
EV load (kW)	264.12	
Maximum EV load		
EV peak (kW)	611.50	
Time	21:30	
Feeder load (MW)	3.10	
EV peak % of feeder load	19.72%	
Energy consumption		
Energy consumption by feeder (MWh)	88.55	
Energy consumption by EV (MWh)	4.80	
% Energy consumption by EV	5.42%	
Energy Supplied		
By Grid (MWh)	88.55	
By Solar PV (MWh)	-	
11kV feeder loss		
Unit	(MWh)	(%)
Case 3 (MWh)	2.626	2.97%

11kV feeder loading (A) with EV load and a public charger in the system is presented in Figure 8.1.24.

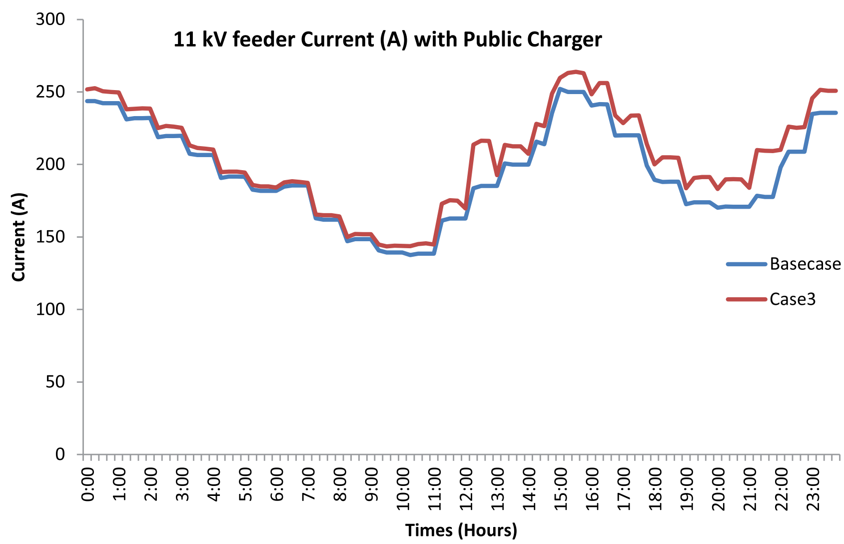


Figure 8.1.24: 11 kV feeder current profile with EV loads and a public charger

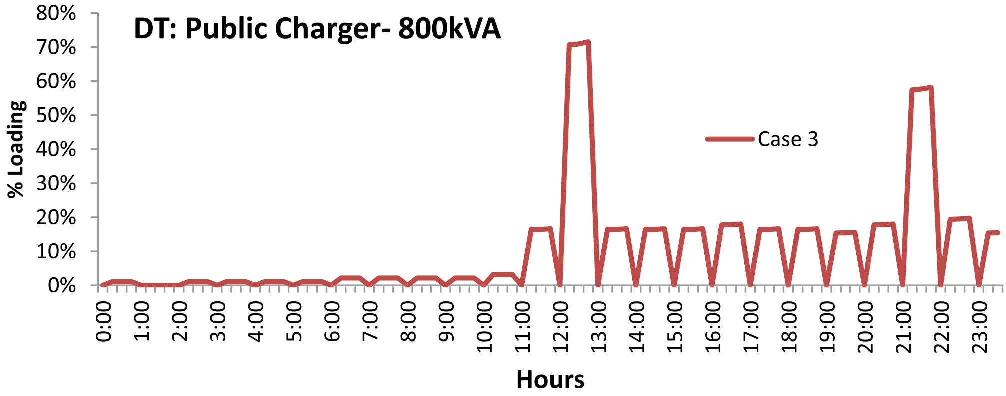


Figure 8.1.25: Transformer % loading at Public charging station

The public charging transformer loading pattern observed is presented in Figure 8.1.25. Power drawl is significantly less in the early hours of the day due to 1 or 2 vehicles are scheduled for charging. As the day progresses the DT loading increases due to multiple vehicles charging at the public charging station. Since the initial SOC of 25% is considered and the vehicles are plugged in for the entire time slot in the simulation, the loading pattern of DT is obtained as in Figure 8.1.25 because EV draws more power initially in constant current mode until the SOC of the battery reaches a certain level and switches over from constant current mode to constant voltage mode where power drawl is lesser.

8.1.2.6 Case 4: EV Penetration of Additional 100% More Than Anticipated

This case is simulated with twice the number of EVs projected in Case-1 to find the impact on the feeder for worst case. Total EVs considered for the year 2030 in Arya samaj feeder and total charges is presented in Figure 8.1.26. Distribution of charging of each vehicle category at different charging locations is furnished in Figure 8.1.27. Distribution of charges per day at different charging locations for each vehicle category remains same as case-1.

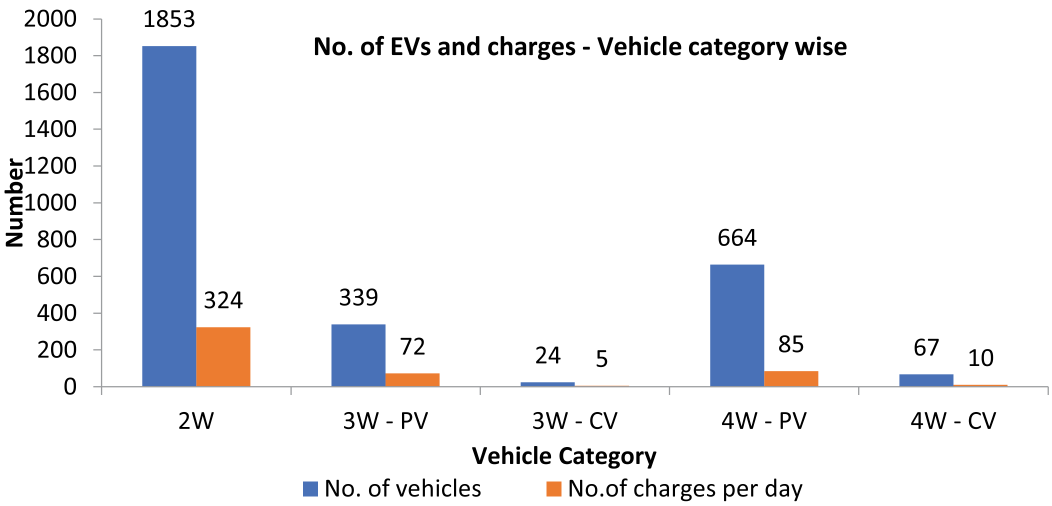


Figure 8.1.26: No. of EVs and charges - Vehicle category wise

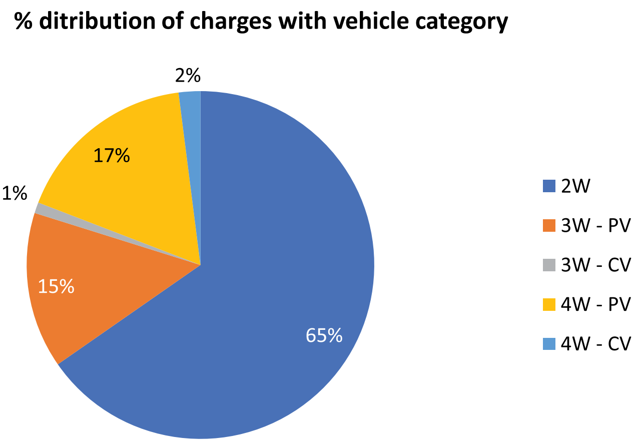


Figure 8.1.27: % distribution of charges with vehicle category

Total number of EV charges per day considered in Arya samaj feeder for 2030 is furnished in Table 8.1.14.

Table 8.1.14: Total EV charges per day considered in Arya samaj feeder for 2030

Vehicle category	Home charging	Office/Work charging	Mall/ Parking charging
2W	214	105	5
3W - PV	63	-	9
3W - CV	4	-	1
4W - PV	56	28	1
4W - CV	8	1	1
Bus	-	-	-

Total number of EV charges considered per day for different vehicle categories are distributed throughout the day in different time slots, from TS1 to TS24. EVs are plugged in at different poles under different DTs randomly. The random distribution has been selected as EV penetration under each DT will not follow uniform distribution in the future times. Random distribution of EVs for each DT in Arya samaj feeder throughout the day for different time slots is presented in Table 8.1.15.

Table 8.1.15: Random distribution of EVs for each DT in Arya samaj for 2030 (More than anticipated)

Random distribution of EVs under each DT		
Name of the DT	**No. of EVs plugged in a day**	**Cumulative battery capacity (kWh)**
TRF-1:ARYA SAMAJ ROAD NALA	74	1180
TRF-2:ARYA SAMAJ ROAD NALA	80	1611
TRF-1:R.K.DASS-1 K.BAGH	85	1773
TRF-2:R.K.DASS-1 K.BAGH	81	1840
TRF-1:R.K.DASS-1/2 K.BAGH	85	1702
TRF-2:R.K.DASS-1/2 K. BAGH	88	1572
Total		**9678**

Case study is executed for a period of 24 hours with the selected load profile including the EV loads plugged in at different point of times in a day. Arya samaj 11 kV feeder load profile with EV loads is presented in Figure 8.1.28.

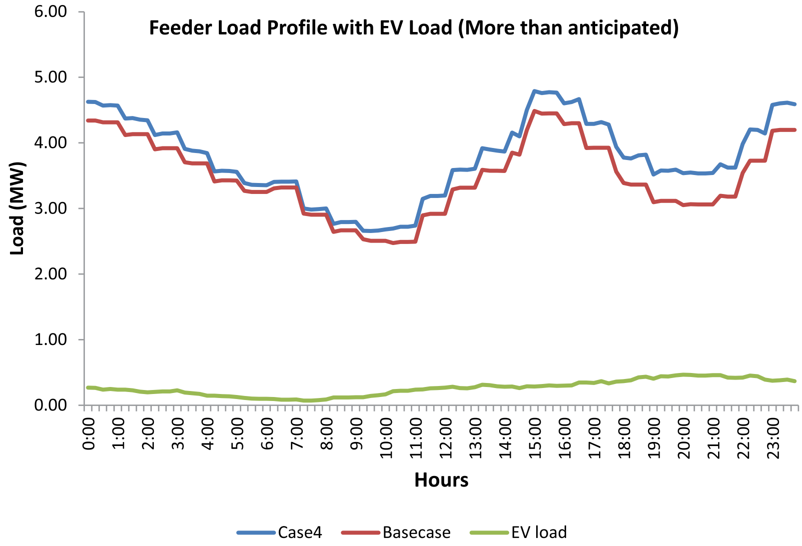


Figure 8.1.28: Arya samaj feeder load profile with EV loads

Peak load of the feeder is 4.79 MW at 15:00 hours and corresponding EV load of 286.76 kW is observed. EV peak load of 468.55 kW is observed at 20:00 hours and corresponding feeder loading is 2.97MW (15.75% of feeder load).

Total energy consumed by feeder is 90.27 MWh with the contribution of 6.39 MWh by the connected EV loads, which corresponds to 7.08% of feeder daily energy consumption. Summary of the observations are presented in Table 8.1.16.

Table 8.1.16: Arya samaj 2030 observations for Case 4

Feeder peak	
Feeder peak load (MW)	4.79
Time	15:00
EV load (kW)	286.76
Maximum EV load	
EV peak (kW)	468.55
Time	20:00
Feeder load (MW)	2.97
EV peak % of feeder load	15.75%
Energy consumption	
Energy consumption by feeder (MWh)	90.27
Energy consumption by EV (MWh)	6.39
% Energy consumption by EV	7.08%
Energy Supplied	
By Grid (MWh)	90.27
By Solar PV (MWh)	-

11kV feeder loss		
Unit	(MWh)	(%)
Case 4 (MWh)	2.760	3.06%

It is observed from Table 8.1.16 that the feeder load profile changes with the addition of EVs and adds to the existing loading in the system. 11kV feeder loading current (A) with EV and without EVs in the system is presented in Figure 8.1.29.

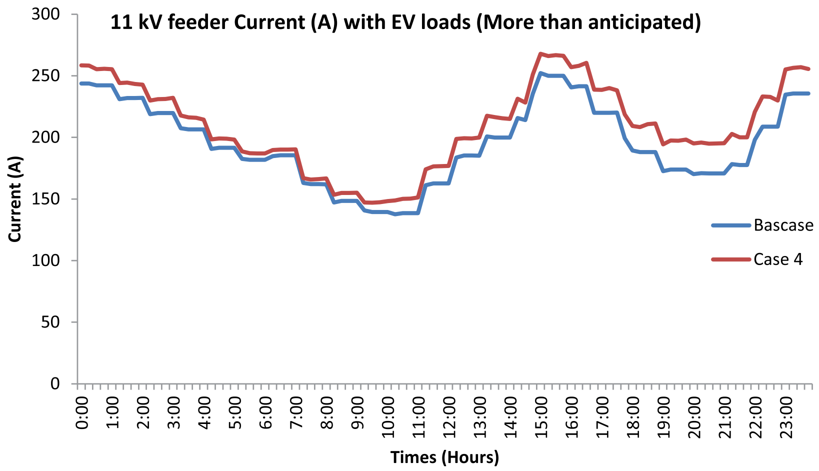


Figure 8.1.29: 11 kV feeder current profile with EV loads

Arya samaj consists of 6 distribution transformers and the loading of some of the transformers throughout the day with EV load in the feeder is presented from Figure 8.1.30 to Figure 8.1.32

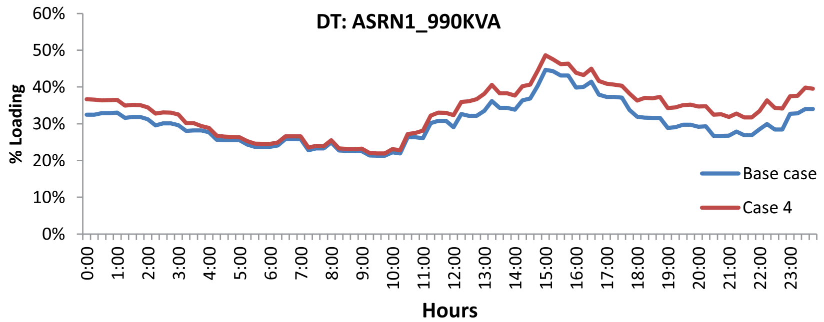


Figure 8.1.30: Transformer % loading of ASRN_HT1_990kVA

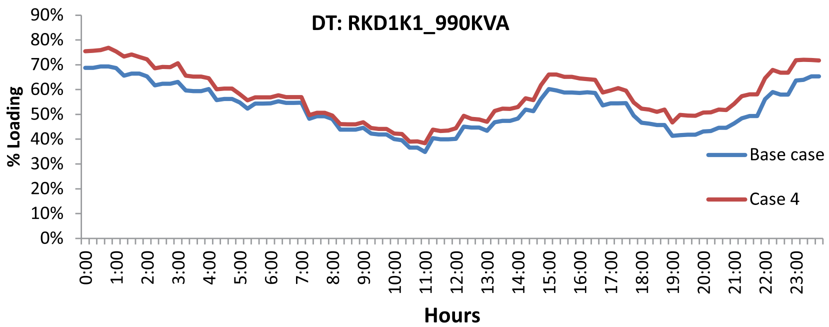


Figure 8.1.31: Transformer % loading of RKD1KHT1_990kVA

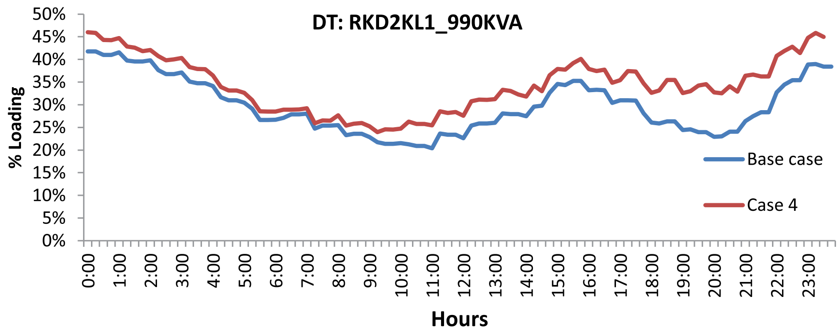


Figure 8.1.32: Transformer % loading of RKD2KHT1_990kVA

From the simulation results, it is observed that high EV penetration under the DTs (ASRN1_990KVA, RKD2K1_990KVA & RKD2KL1_990KVA) has its impact on loading as compared to other DTs. Also the impact of loading varies as per the charging behaviour and connected EVS under DTs.

8.1.2.7 Case 5: EV penetration with Public Charging Station (EVs 100% More Than Anticipated)

The impact of higher EV penetration (twice the expected EVs) with public charger is addressed in this section.

In addition to EV's distributed across Arya samaj as furnished in Table 8.1.15, vehicles distribution throughout the day for DT in public charging station is given in Table 8.1.12.

Table 8.1.17: Random distribution of EVs under Public Charger DT in Arya Samaj for 2030 (More than anticipated)

Name of the DT	No of EV's	Cumulative battery capacity (kWh)
DT-Public Charging	191	4267

The load profile of the feeder is presented in Figure 8.1.33.

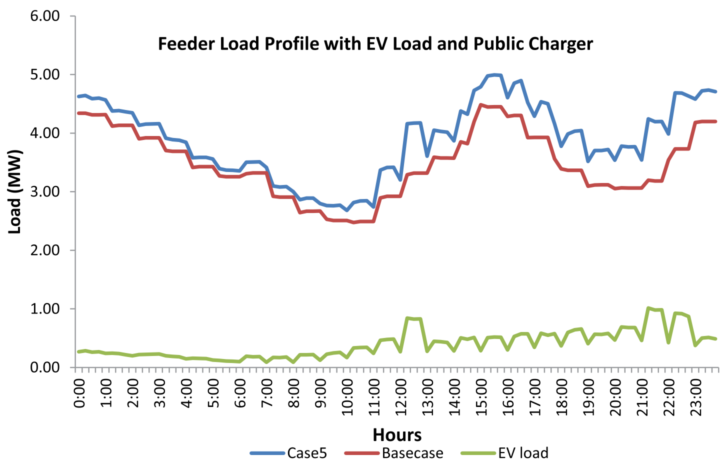


Figure 8.1.33: Arya samaj feeder load profile with EV loads and a public charger

Peak load of the feeder is 4.99 MW at 15:30 hours and corresponding EV load of 520.92 kW is observed. EV peak load of 1014.02 kW is observed at 21:15 hours and corresponding feeder loading is 3.11MW (32.56% of feeder load).

Total energy consumed by feeder is 93.41 MWh with the contribution of 9.47 MWh by the connected EV loads, which corresponds to 10.14% of feeder daily energy consumption. Energy loss is 3.01%, 2.81 MWh with EV load and summary of the observations are presented in Table 8.1.18.

Table 8.1.18: Arya samaj 2030 observations for Case 5

Feeder peak		
Feeder peak load (MW)	4.99	
Time	15:30	
EV load (kW)	520.92	
Maximum EV load		
EV peak (kW)	1014.02	
Time	21:15	
Feeder load (MW)	3.11	
EV peak % of feeder load	32.56%	
Energy consumption		
Energy consumption by feeder (MWh)	93.41	
Energy consumption by EV (MWh)	9.47	
% Energy consumption by EV	10.14%	
Energy supplied		
By Grid (MWh)	93.41	
By Solar PV (MWh)	-	
11kV feeder loss		
Unit	(MWh)	(%)
Case 5 (MWh)	2.815	3.01%

11kV feeder loading (A) with EV load and a public charger in the system is presented in Figure 8.1.34.

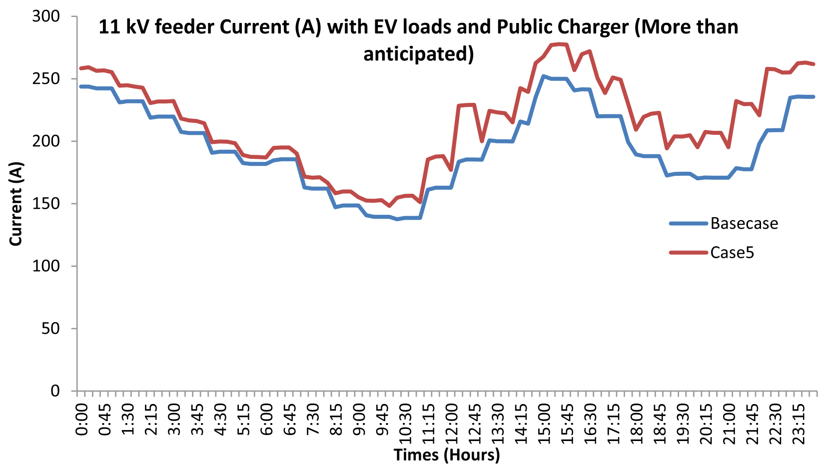


Figure 8.1.34: 11 kV feeder current profile with EV loads and a public charger (More than anticipated)

8.1.2.8 Case 6: EV Penetration with Public Charger (EV 100% More Than Anticipated) with TOU (Time of Usage) Tariff

In this case, vehicles charging at all places including public charger are made to plug-in during the time when solar is high. The charging behaviour considered in methodology as presented in

Table 8.2.8 is modified to support ToU tariff. It is assumed that 80% of EVs will connect to the grid during high solar period.

Arya samaj feeder network with EV penetration and typical solar generation as considered in case2A is considered. Arya samaj, 11 kV feeder load profile with EV loads with TOU and solar rooftop generation is presented in Figure 8.1.35.

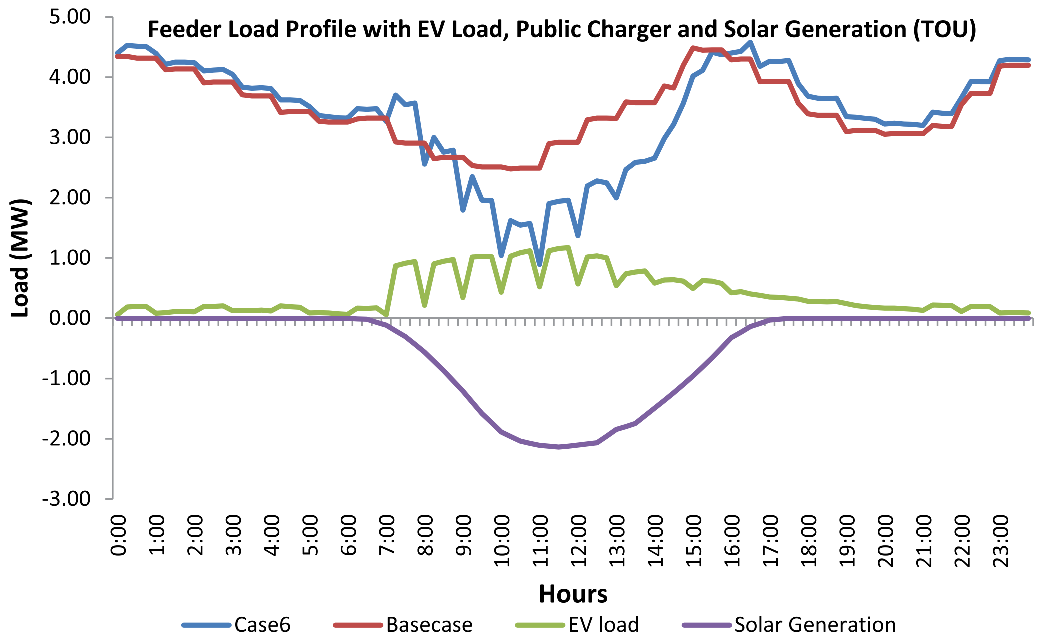


Figure 8.1.35: Arya samaj feeder load profile with EV loads and solar penetration

It is observed from Figure 8.1.35 that energy drawn from the grid reduces significantly with solar generation in the feeder. During this period 80% of the EVs are made to plug-in. It can be noted that most of the EVs are charging during high solar period and the stress on the system can be reduced during peak time.

Peak load of the feeder is 4.58 MW at 16:30 hours and corresponding EV load of 403.26 kW is observed. EV peak load of 1173.4 kW is observed at 11:45 hours and corresponding feeder loading is 2.85MW (41.13% of feeder load).

Total energy consumed by feeder is 93.49 MWh with the contribution of 9.82 MWh by the connected EV loads, which corresponds to 10.5% of feeder daily energy consumption. Energy loss is 2.73%, 2.55 MWh with EV load and summary of the observations are presented in Table 8.1.18.

Table 8.1.19: Arya samaj 2030 observations for Case 6

Feeder peak		
Feeder peak load (MW)	4.58	
Time	16:30	
EV load (kW)	403.26	
Maximum EV load		
EV peak (kW)	1173.40	
Time	11:45	
Feeder load (MW)	2.853	
EV peak % of feeder load	41.13%	
Energy consumption		
Energy consumption by feeder (MWh)	93.49	
Energy consumption by EV (MWh)	9.82	
% Energy consumption by EV	10.50%	
Energy supplied		
By Grid (MWh)	80.74	
By Solar PV (MWh)	12.75	
11kV feeder loss		
Unit	(MWh)	(%)
Case 6 (MWh)	2.55	2.73%

11kV feeder loading (A) with EV load and a public charger in the system is presented in Figure 8.1.36

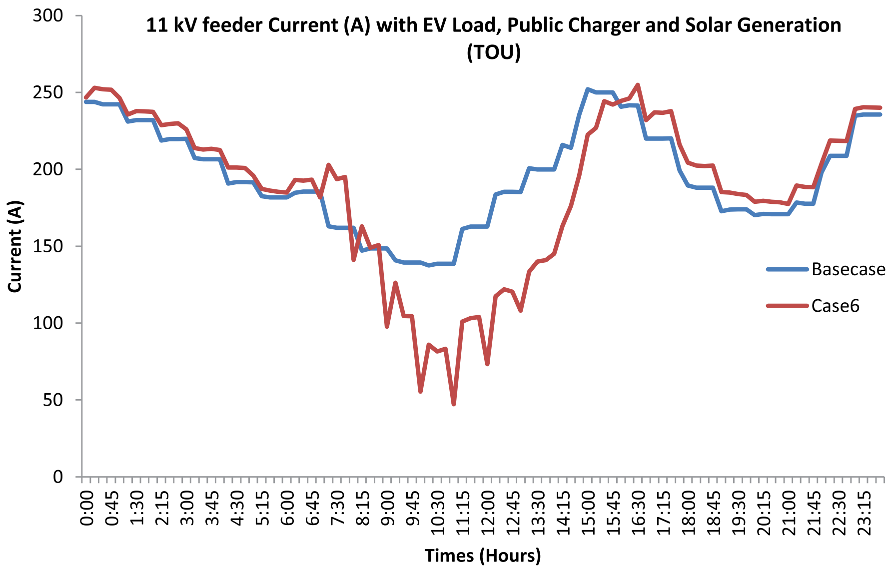


Figure 8.1.36: 11 kV feeder current profile with EV loads and a public charger (More than anticipated)

8.1.2.9 Case 7: EV Penetration with Grid Storage System

In this case, vehicles charging profile of Case-5 is retained and battery storage of capacity 1MWh is considered in the system. Battery is charged during the peak solar time and discharged during peak EV charging time.

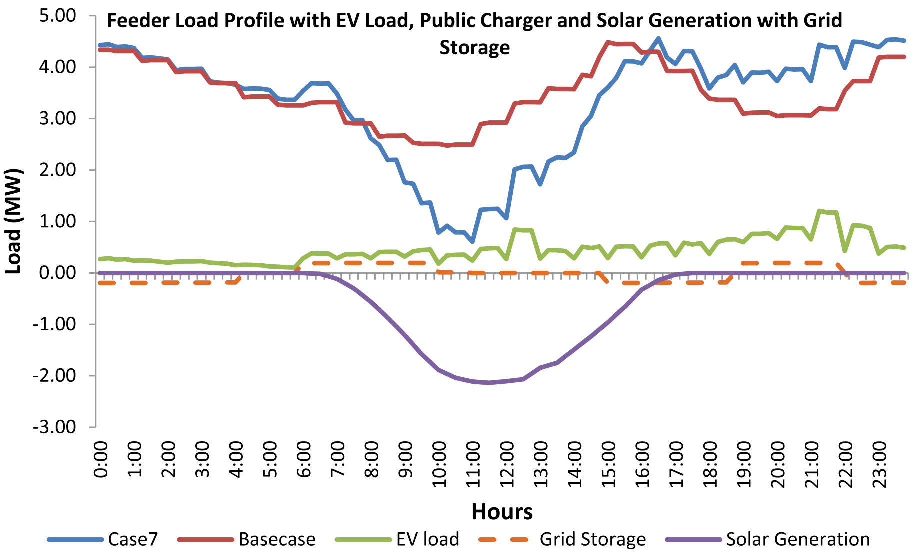


Figure 8.1.37: Arya samaj feeder load profile with EV loads, solar penetration and grid storage

It is observed from Figure 8.1.37 that the battery is charged during peak solar time with charging rate of 0.2C and is discharged during peak load and hence reducing the burden on the grid during that time.

Peak load of the feeder is 4.56 MW at 16:30 hours and corresponding EV load of 573.55 kW is observed. EV peak load of 1206.1 kW is observed at 21:15 hours and corresponding feeder loading is 3.11MW (38.73% of feeder load).

Total energy consumed by feeder is 92.65 MWh with the contribution of 10.82 MWh by the connected EV loads, which corresponds to 11.68% of feeder daily energy consumption. Energy loss is 2.76%, 2.56 MWh with EV load and summary of the observations are presented in Table 8.1.18.

Table 8.1.20: Arya samaj 2030 observations for Case 7

Feeder peak	
Feeder peak load (MW)	4.56
Time	16:30
EV load (kW)	573.55
Maximum EV load	
EV peak (kW)	1206.10
Time	21:15
Feeder load (MW)	3.114
EV peak % of feeder load	38.73%

Energy consumption		
Energy consumption by feeder (MWh)	92.65	
Energy consumption by EV (MWh)	10.82	
% Energy consumption by EV	11.68%	
Energy supplied		
By Grid (MWh)	79.90	
By Solar PV (MWh)	12.75	
11kV feeder loss		
Unit	(MWh)	(%)
Case 7 (MWh)	2.56	2.76%

11kV feeder loading (A) with EV load and a public charger in the system is presented in Figure 8.1.38

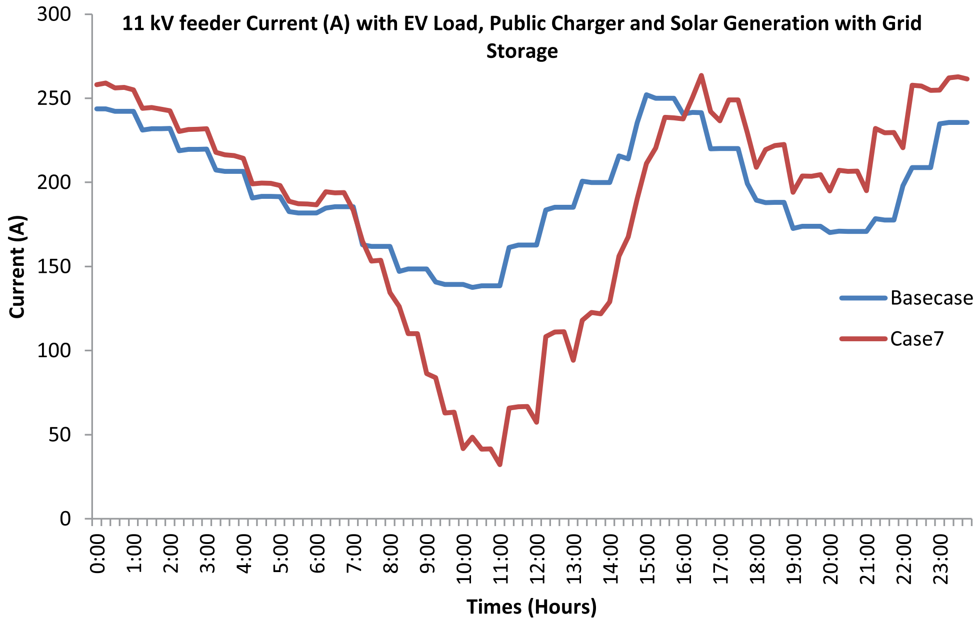


Figure 8.1.38: 11 kV feeder Current (A) with EV Load, Public Charger and Solar Generation with Grid Storage

8.1.2.10 Case 8: EV Penetration with EV Battery Capacity as per Present Battery Technologies in India

This case is executed for EV battery sizes as per current availability in Indian markets. Existing EV battery sizes considered for different vehicle category is presented in Table 8.1.21. With lesser battery capacity in EV, the range is lesser and the frequency of charging the vehicle is high. Considering initial SOC to be 25%, number of charges per vehicle category per year is presented in Table 8.1.21.

Table 8.1.21: EV Battery capacities considered as per existing trend in India

Vehicle Category	Battery Capacity (kWh)	No. of charges per year per vehicle
2W	1.5	130
3W - PV	4	608

3W - CV	7	389
4W - PV	15	145
4W - CV	15	886
Bus	120	811

Total EV considered in 2030 in Arya samaj feeder and total charges is presented in Figure 8.1.39. Distribution of charging of each vehicle category at three (Home, Office/Work & Mall/Parking) different charging locations is furnished in Figure 8.1.39

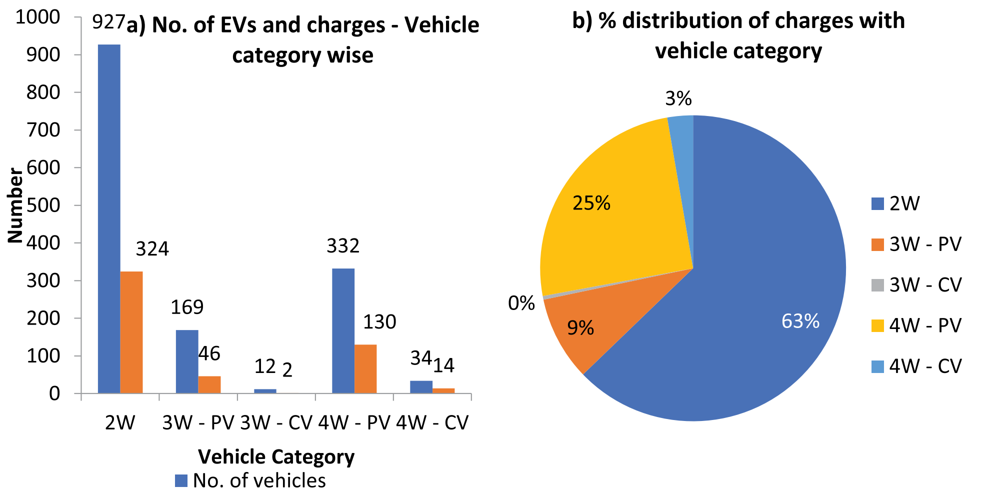


Figure 5.1.39: a) No. of EVs and charges - Vehicle category wise b) % distribution of charges with vehicle category

Total number of EV charges per day considered in Arya samaj feeder for 2030 is furnished in Table 8.1.22.

Table 8.1.22: Total EV charges per day considered in Arya samaj feeder for 2030

Vehicle category	Home charging	Office/Work charging	Mall/ Parking charging
2W	214	105	5
3W - PV	40	-	6
3W - CV	2	-	-
4W - PV	86	42	2
4W - CV	11	2	1
Bus	-	-	-

Total number of EV charges considered per day for different vehicle categories are distributed throughout the day in different time slots, from TS1 to TS24. EVs are plugged in at different poles under different DTs randomly. The random distribution has been selected as EV penetration under each DT will not follow uniform distribution in the future times. Random distribution of EVs for each DT in Arya samaj feeder throughout the day for different time slots is presented in Table 8.1.23.

Table 8.1.23: Random distribution of EVs for each DT in Arya samaj for 2030 (Low battery capacity))

Random distribution of EVs under each DT		
Name of the DT	**No. of EVs plugged in a day**	**Cumulative battery capacity (kWh)**
TRF-1:ARYA SAMAJ ROAD NALA	72	398
TRF-2:ARYA SAMAJ ROAD NALA	93	567
TRF-1:R.K.DASS-1 K.BAGH	92	542
TRF-2:R.K.DASS-1 K.BAGH	89	548
TRF-1:R.K.DASS-1/2 K.BAGH	77	453
TRF-2:R.K.DASS-1/2 K. BAGH	92	513
Total		**3019**

Case study is executed for a period of 24 hours with the selected load profile including the EV loads plugged in at different point of times in a day.

Arya samaj 11 kV feeder load profile with EV loads is presented in Figure 8.1.40.

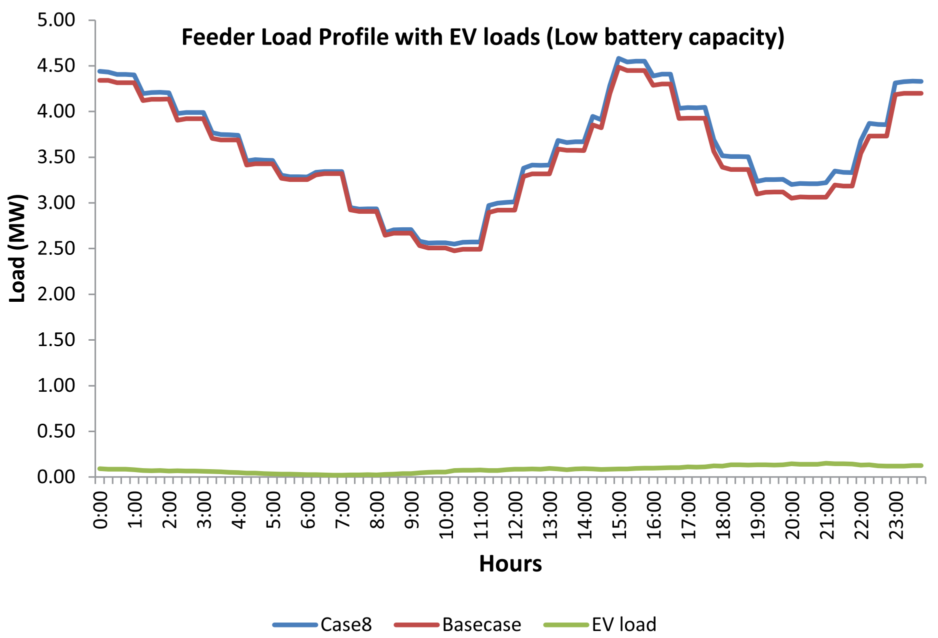


Figure 8.1.40: Arya samaj feeder load profile for case-8

Peak load of the feeder is 4.58 MW at 15:00 hours and corresponding EV load of 89.94 kW is observed. EV peak load of 151.68 kW is observed at 21:00 hours and corresponding feeder loading is 2.99MW (5.08% of feeder load).

Total energy consumed by feeder is 85.68 MWh with the contribution of 2.01 MWh by the connected EV loads, which corresponds to 2.34% of feeder daily energy consumption. Energy loss is 2.98%, 2.55 MWh with EV load and summary of the observations are presented in Table 8.1.24.

Table 8.1.24: Arya samaj 2030 observations for Case 8

Feeder peak		
Feeder peak load (MW)	4.58	
Time	15:00	
EV load (kW)	89.94	
Maximum EV load		
EV peak (kW)	151.68	
Time	21:00	
Feeder load (MW)	2.99	
EV peak % of feeder load	5.08%	
Energy consumption		
Energy consumption by feeder (MWh)	85.68	
Energy consumption by EV (MWh)	2.01	
% Energy consumption by EV	2.34%	
Energy Supplied		
By Grid (MWh)	85.68	
By Solar PV (MWh)	-	
11kV feeder loss		
Unit	(MWh)	(%)
Case 8 (MWh)	2.55	2.98%

11kV feeder loading (A) with EV load and typical solar generation in the system is presented in Figure 8.1.41. From the results of case 1 and case 8 where higher and lower capacity batteries are considered for analysis, it is observed that the impact on grid is more with high capacity battery EVs. This is due to drawl of large current from the grid when high capacity EV is connected to grid even though the number of high capacity EVs connected to the grid is less compared with low capacity EVs.

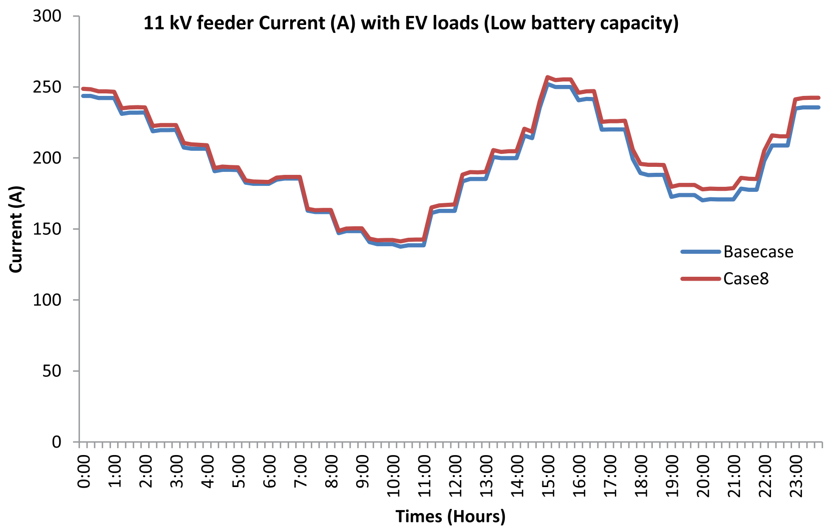


Figure 8.1.41: 11 kV feeder current profile for case-8

8.1.2.11 Summary of Results for Arya samaj

Summary of Arya samaj cases for the year 2030 is furnished in Table 8.1.26. From the simulation results, it can be observed that the increase in feeder load is around 199 kW and 144 kW when high capacity and low capacity batteries penetrates in the feeder for the year 2030 respectively. The projected EV penetration has minimal impact on distribution feeder for the year 2030. In terms of energy, EVs contribute for around 4.22% and 3.10% of daily feeder energy with and without public charging station respectively in Arya samaj feeder. In addition, additional solar rooftop generation will relieve the grid and allows while promoting the public, mall and office charging facilities by imposing Time of Usage (ToU) tariff. Hence EV penetration impacts on feeder are very minimal as compared with feeder load and its growth.

8.1.2.12 Additional Case Study for Winter Load Profile for the Year 2030

Arya samaj feeder network with EV penetration is considered and simulated for a period of 24 hours. No of vehicles and vehicle distribution remains same as in case-1. Arya samaj, 11 kV feeder load profile with EV loads and solar rooftop generation is presented in Figure 8.1.42.

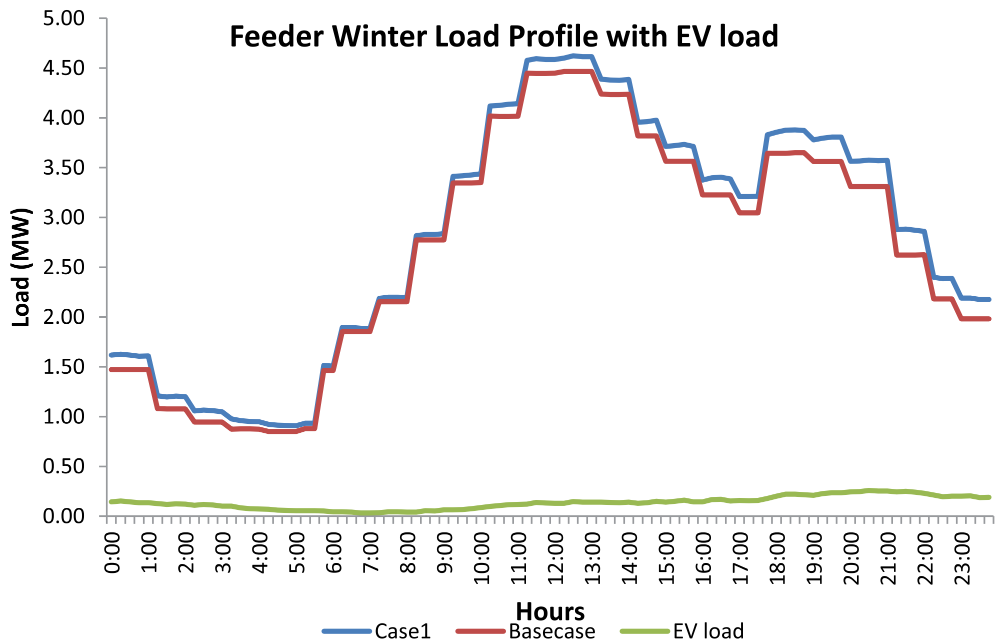


Figure 8.1.42: Arya samaj feeder winter load profile with EV load

Peak load of the feeder is 4.62 MW at 12:30 hours and corresponding EV load of 147.84 kW is observed. EV peak load of 257.02 kW is observed at 20:30 hours and corresponding feeder loading is 3.23MW (7.96% of feeder load).

Total energy consumed by feeder is 67.85 MWh with the contribution of 3.24 MWh by the connected EV loads, which corresponds to 4.78% of feeder daily energy consumption. Energy loss is 2.34%, 1.59 MWh with EV load. Summary of the observations are presented in Table 8.1.25

Table 8.1.25: Arya samaj 2030 observations for Case-1, winter load profile

Feeder peak		
Feeder peak load (MW)	4.62	
Time	12:30	
EV load (kW)	147.84	
Maximum EV load		
EV peak (kW)	257.02	
Time	20:30	
Feeder load (MW)	3.23	
EV peak % of feeder load	7.96%	
Energy consumption		
Energy consumption by feeder (MWh)	67.85	
Energy consumption by EV (MWh)	3.24	
% Energy consumption by EV	4.78%	
Energy supplied		
By Grid (MWh)	67.85	
By Solar PV (MWh)	-	
11kV feeder loss		
Unit	(MWh)	(%)
Case 1 (MWh)	1.59	2.34%

11kV feeder loading (A) with EV load and typical winter load profile in the system is presented in Figure 8.1.43.

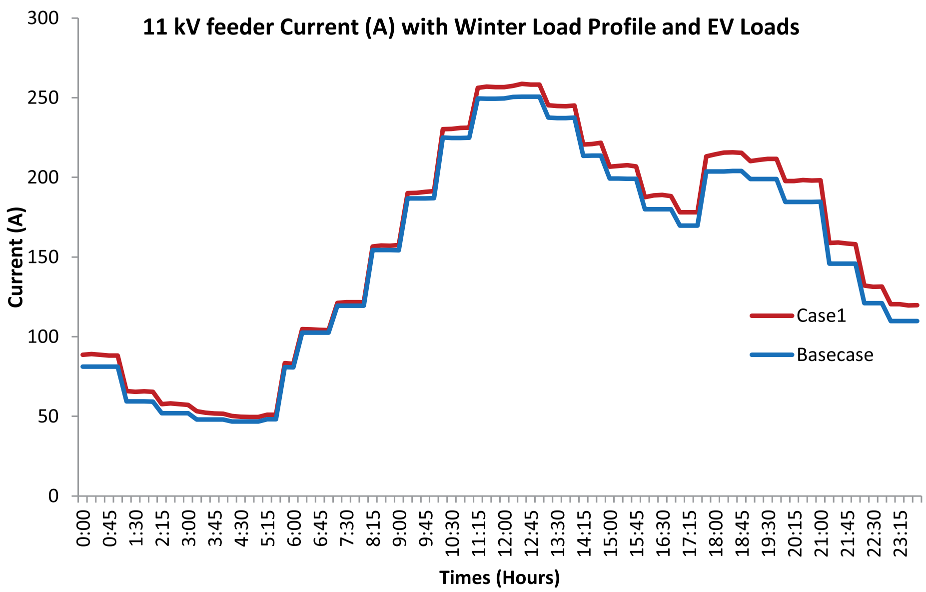


Figure 8.1.43: 11 kV feeder current profile with EV loads and typical winter load profile

Table 8.1.26: Summary of observations of Arya samaj cases for 2030

Observation		Base case	Case 1 (25% SOC)	Case 1A (60% SOC)	Case 2A	Case 2B	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
BC		**BC+EV**	**BC+EV**	**BC+EV+PV1**	**BC+EV+PV2**	**BC+EV+PC**	**BC+EV (100%)**	**BC+EV (100%) + PC**	**BC+EV (100%) + PC (TOU)**	**BC+EV+ Battery**	**BC+EV (LC)**	
Feeder peak												
Feeder peak load	MW	4.49	4.63	4.64	4.50	4.50	4.72	4.79	4.99	4.58	4.56	4.58
Time	Hrs.	15:00	15:00	15:00	0:15	0:15	15:30	15:00	15:30	16:30	16:30	15:00
EV load	kW	-	140.39	147.59	152.71	152.71	264.12	286.76	520.92	403.26	573.55	89.94
Maximum EV load												
EV peak	kW	-	257.02	226.85	257.02	257.02	611.50	468.55	1014.02	1173.40	1206.10	151.68
Time	Hrs.	-	20:30	19:45	20:30	20:30	21:30	20:00	21:15	11:45	21:15	21:00
Feeder load	MW	-	2.99	3.04	2.99	2.99	3.10	2.97	3.11	2.85	3.11	2.99
EV peak % of feeder load	%	-	8.60%	7.47%	8.60%	8.60%	19.72%	15.75%	32.56%	41.13%	38.73%	5.08%
Energy consumption												
Energy consumption by feeder	MWh	83.58	86.97	86.73	86.73	86.74	88.55	90.27	93.41	93.49	92.65	85.68
Energy consumption only by EV	MWh	-	3.24	3.01	3.24	3.24	4.80	6.39	9.47	9.82	10.82	2.01

% Energy by EV	%	-	3.73%	3.47%	3.74%	3.74%	5.42%	7.08%	10.14%	10.50%	11.68%	2.34%
Energy supplied												
By Grid	MWh	83.58	86.97	86.73	73.98	75.03	88.55	90.27	93.41	80.74	79.90	85.68
By Solar PV	MWh	-	-	-	12.75	11.71	-	-	-	12.75	12.75	-
11kV Feeder loss												
Loss	MWh	2.46	2.60	2.60	2.37	2.38	2.63	2.76	2.81	2.55	2.56	2.55
% Loss	%	2.94%	2.99%	3.00%	2.73%	2.74%	2.97%	3.06%	3.01%	2.73%	2.76%	2.98%

The simulations carried out for the years 2023 and 2019 for Arya Samaj feeder are provided in section 8.4 of Annexure

8.1.2.13 Impact of EV on Voltage Profile

With addition of electric vehicles to the distribution system the voltage profile of the HT points (11kV HT points for transformers at 3 different locations and one Public Charger) in the Arya samaj feeder is plotted for peak EV instant for both base case & case 3. The same is furnished in the Figure 8.1.44.

The graph is plotted such that it starts from HT point nearest to the 11kV grid and ends with HT point farthest to the 11kV grid. To observe the dynamic voltage profile, the HT point farthest to the grid is considered and the voltage plotted for the whole day (24 hours) and is furnished in Figure 8.1.45.

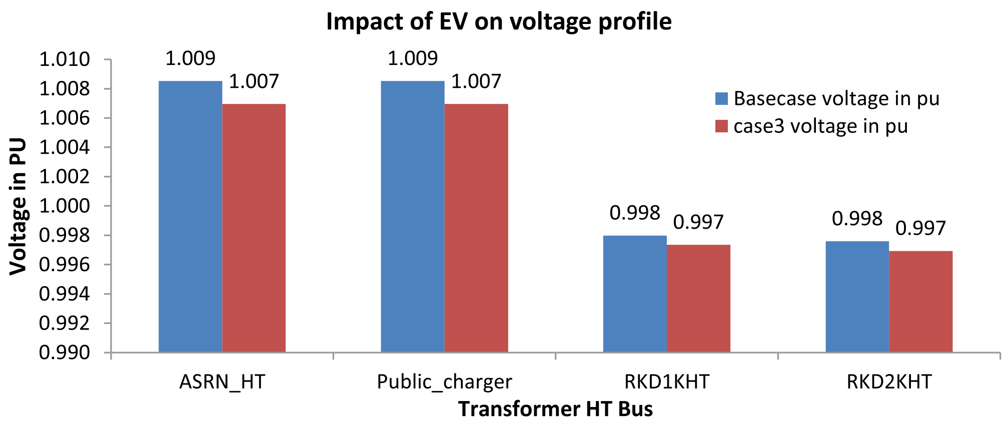


Figure 8.1.44: Voltage profile of HT points in the feeder plotted for EV peak load instant

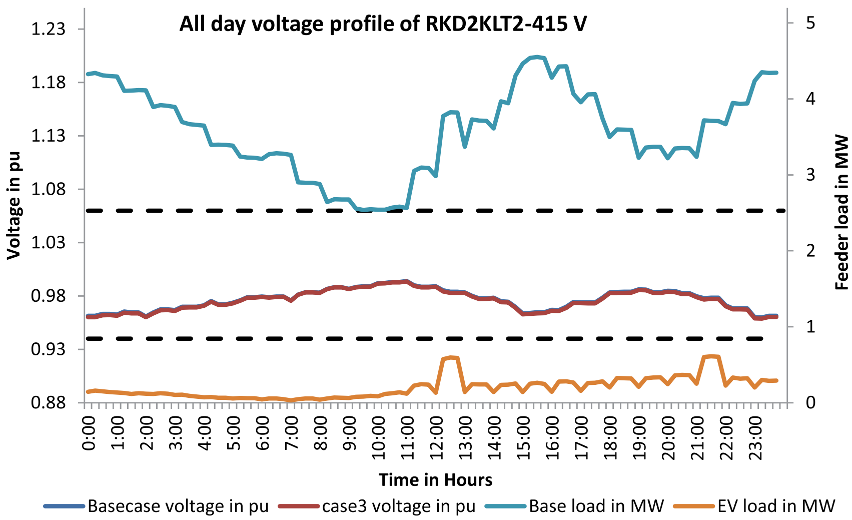


Figure 8.1.45: Voltage profile of tail end HT point in the feeder plotted for 24 hours

It can be observed from Figure 8.1.44 and Figure 8.1.45 that the impact on voltage due to EV load is very minimal as long as the voltage at the 11kV is maintained at 1 PU. The two dotted lines in the graph indicates upper and lower limits as per DERC Distribution Code [2017], i.e. ±6% in the case of low tension. From the simulations it can be observed that the voltage is within the acceptable limits. It can also be inferred that the public charger can be installed at any location in the feeder as the impact on voltage profile is very minimal.

8.2 Janta Colony Feeder

Janta colony, 11 kV feeder emanates from 33/11 kV Dwarakapuri substation and consists of 10 distribution transformers at 7 different locations. Janta colony feeder consists of 3767 connections in total, which contributes to 0.22% of total BYPL connections. Janta colony feeder network is presented in Figure 5.4.1. Total number of EVs projected for Janta colony feeder for future years considered from Table 7.2.3 is shown in

Figure 8.2.1.

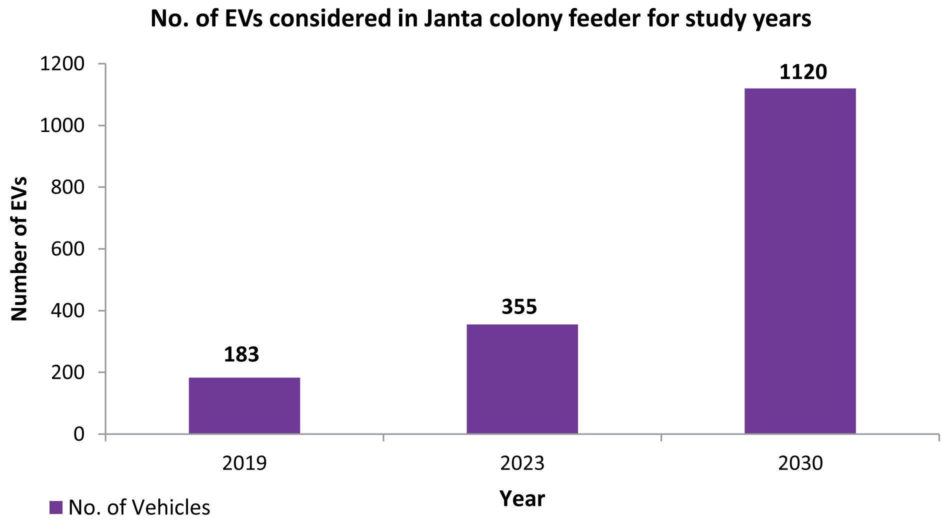


Figure 8.2.1: Total number of EVs projected for Janta colony feeder for future years

8.2.1 Base Case

Janta colony feeder network is modelled with the existing loads as per the selected load profile. Typical daily load profile for Janta colony feeder for the month of June is considered since Delhi peak and BYPL peak were observed in the month of June. Feeder peak of 3.81 MW is observed for Janta colony feeder in 2018 and the same is considered with the selected load profile as shown in Figure 8.2.2.

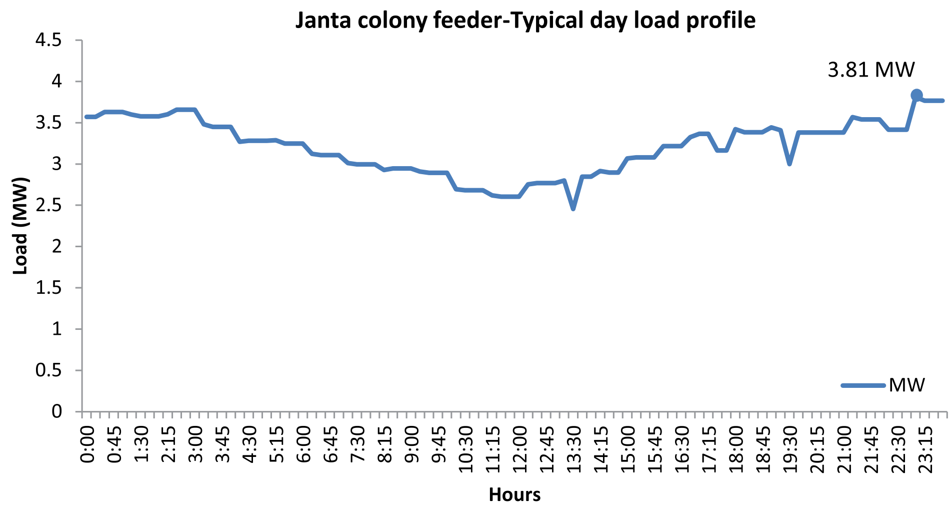


Figure 8.2.2: Janta colony feeder-Typical day load profile

Sanctioned loads are modelled at each pole and scaled to match phase imbalance and DT loading for every 15 minutes interval as per the available feeder loading. Transformer loading in base case for peak instant is presented in Table 8.2.1.

Table 8.2.1: Janta colony transformer loading in base case at peak instant

Transformer name	Transformer Capacity (MVA)	Transformer loading at feeder peak (MW)	Simulated results of transformer loading (MW)	Error %
JANTA_COLONY_NO-5_TRF1	0.63	0.382	0.387	1.24
JANTA_COLONY_NO-6_TRF	0.63	0.442	0.447	1.27
JANTA_COLONY_NO-3_TRF	0.63	0.303	0.311	2.81
JANTA_COLONY_NO-7_TRF1	0.63	0.482	0.494	2.59
JANTA_COLONY_NO-4_TRF1	0.63	0.415	0.42	1.36
JANTA_COLONY_NO-5_TRF	0.4	0.25	0.254	1.4
JANTA_COLONY_NO-2_TRF	0.4	0.11	0.112	1.04
JANTA_COLONY_NO-1_TRF	0.63	0.73	0.765	4.84
JANTA_COLONY_NO-7_TRF2	0.63	0.309	0.316	2.27
JANTA_COLONY_NO-4_TRF2	0.63	0.387	0.398	2.88

Nomenclature for transformers in Janta colony feeder has been used for convenience, as presented in

Table 8.2.2.

Table 8.2.2: Transformer nomenclature

Transformer name	Nomenclature
JANTA_COLONY_NO-1_TRF	JCN1_PM_630KVA
JANTA_COLONY_NO-2_TRF	JCN2_400KVA
JANTA_COLONY_NO-3_TRF	JCN3_PM_630KVA
JANTA_COLONY_NO-4_TRF1	JCN4_PL1_630KVA
JANTA_COLONY_NO-4_TRF2	JCN4_PL2_630KVA
JANTA_COLONY_NO-5_TRF1	JCN5_PL1_630KVA
JANTA_COLONY_NO-5_TRF2	JCN5_PL2_400KVA
JANTA_COLONY_NO-6_TRF	JCN6_PL_630KVA
JANTA_COLONY_NO-7_TRF1	JCN7_PL1_630KVA
JANTA_COLONY_NO-7_TRF2	JCN7_PL2_630KVA

82.2 Simulation Studies for the Year 2030

Considering the advancement in battery technology and current EV trends in European countries, for the year 2030, higher battery sizes of EVs are considered. With higher EV battery capacity it is natural that the ranges of the EVs are higher which means frequency of charging the EV is lesser. Considering the fact that the average daily distance commuted by all the vehicle categories will be same in the future, total number of charges per vehicle per year **with 25% initial SOC is** calculated. Higher battery capacities considered as per current trends in European countries and their corresponding number of charges per year is presented in Table **8.2.3**. Cases considered for

Janta colony feeder for year 2030 is presented in Figure **8.2.3**. Description of cases considered for Janta colony feeder for year 2030 is presented in

Table 8.2.4

Table 8.2.3: EV Battery capacities considered for year 2030

Vehicle Category	Battery Capacity (kWh)	No. of charges per year per vehicle
2W	4	65
3W - PV	7	487
3W - CV	9	389
4W - PV	80	37
4W - CV	80	227
Bus	250	389

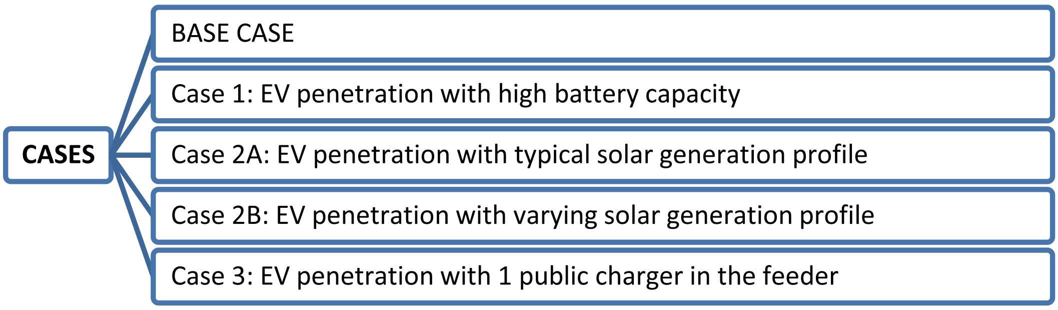


Figure 8.2.3: Cases considered for Janta colony feeder for year 2030

Table 8.2.4: Description for cases considered for Janta colony feeder for year 2030

Case description	EV	Solar profile A	Solar profile B	Public Charger
Case-1	✓	×	×	×
Case-2A	ü	ü	×	×
Case-2B	ü	×	ü	×
Case-3	✓	×	×	✓

8.2.2.1 Case 1: EV Penetration

Total EVs and total charges considered in 2030 are presented in Figure 8.2.4 Distribution of charging of each vehicle category at different charging locations is furnished from Figure 8.2.4 to Figure 8.2.7.

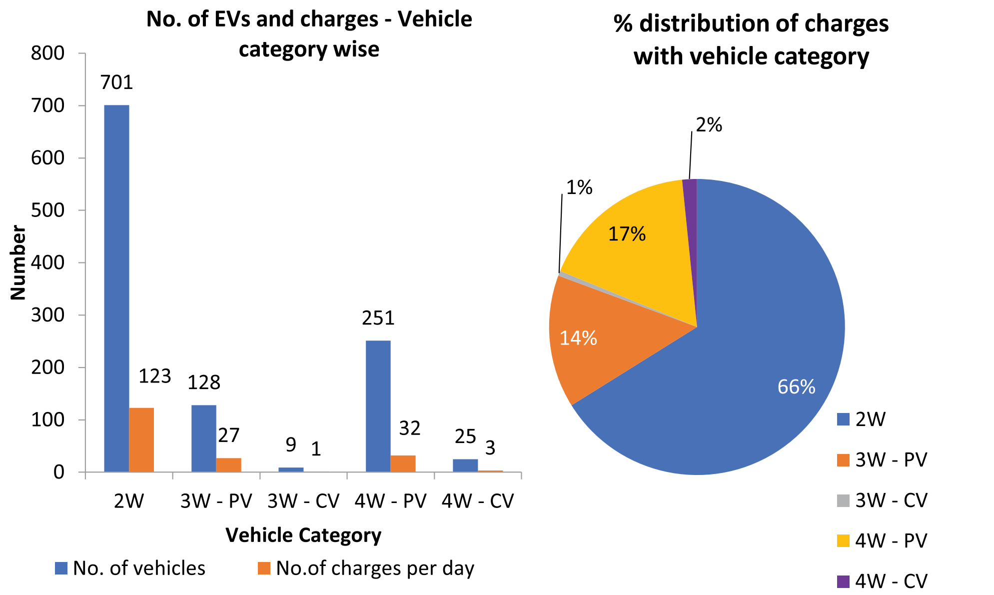


Figure 8.2.4: a) No. of EVs and charges - Vehicle category wise b) % % distribution of charges with vehicle category

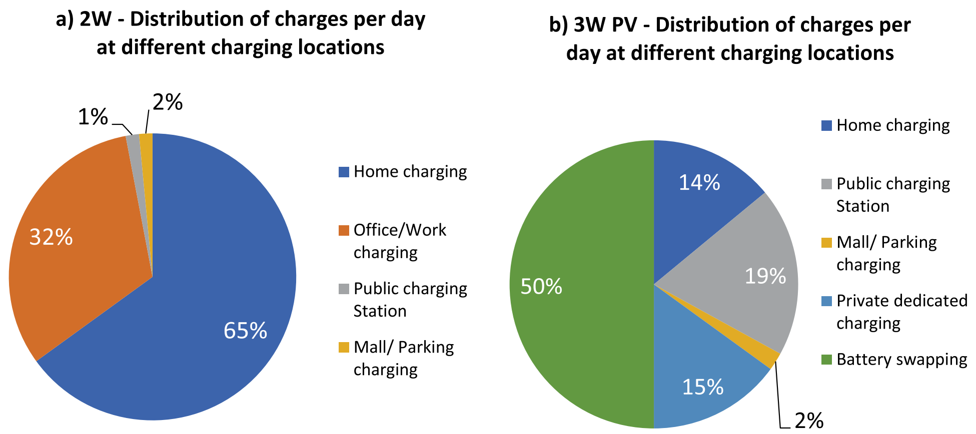


Figure 8.2.5: a) 2W – location wise charge distribution b) 3W PV – location wise charge distribution

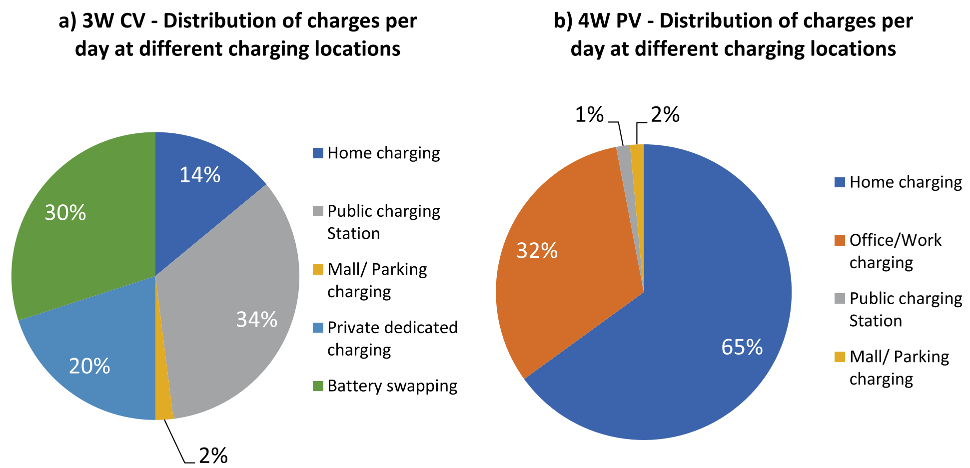


Figure 8.2.6: a) 3W CV – location wise charge distribution b) 4W PV – location wise charge distribution

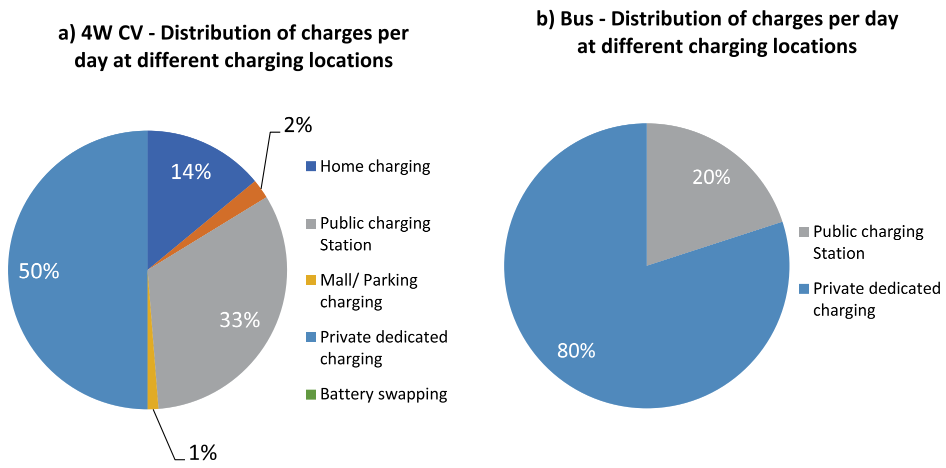


Figure 8.2.7: a) 4W CV – location wise charge distribution b) Bus – location wise charge distribution

Distribution of charges per day at different charging locations for various categories of vehicles remains same as furnished from Figure 8.2.5 to Figure 8.2.7 for all the simulations carried out.

Total number of EV charges per day considered in Janta colony feeder for 2030 is furnished in Table 8.2.5.

Table 8.2.5: Total EV charges per day considered in Janta colony feeder for 2030

Vehicle category	Home charging	Office/Work charging	Mall/ Parking charging
2W	81	40	2
3W - PV	12	-	2
3W - CV	1	-	-
4W - PV	17	8	-
4W - CV	2	-	-
Bus	-	-	-

Total number of EV charges considered per day for different vehicle categories are distributed throughout the day in different time slots, from TS1 to TS24. EVs are plugged in at different poles under different DTs randomly. The random distribution has been selected as EV penetration under each DT will not follow uniform distribution in the future times. Random distribution of EVs for each DT in Janta colony feeder throughout the day for different time slots is presented in Table 8.2.6.

Table 8.2.6: Random distribution of EVs under each DT in Janta colony for 2030

Name of the DT	Random distribution of EV's under each DT	Cumulative battery capacity (kWh)
JCN1_PM_630KVA	15	146
JCN2_400KVA	15	293
JCN3_PM_630KVA	19	390
JCN4_PL1_630KVA	24	420
JCN4_PL2_630KVA	13	66

Name of the DT	Random distribution of EV's under each DT	Cumulative battery capacity (kWh)
JCN5_PL1_630KVA	22	417
JCN5_PL2_400KVA	17	315
JCN6_PL_630KVA	22	706
JCN7_PL1_630KVA	15	454
JCN7_PL2_630KVA	22	336
Total		**3543**

Case study is executed for a period of 24 hours with the selected load profile including the EV loads plugged in at different point of times in a day. Janta colony 11 kV feeder load profile with EV loads is presented in Figure 8.2.8.

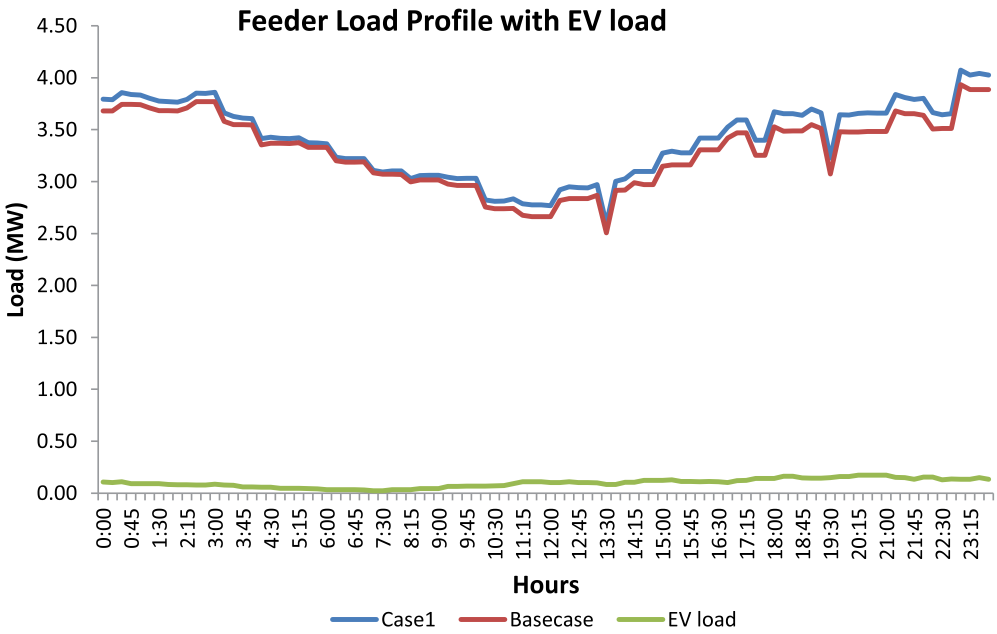


Figure 8.2.8: Janta colony feeder load profile with EV loads

Peak load of the feeder is 4.07 MW at 23:00 hours and corresponding EV load of 134.57 kW is observed. EV peak load of 173.92 kW is observed at 20:15 hours and corresponding feeder loading is 3.38MW (5.15% of feeder load).

Total energy consumed by feeder is 81.59 MWh with the contribution of 2.35 MWh by the connected EV loads, which corresponds to 2.88% of feeder daily energy consumption. Energy loss is 2.7%, 2.21 MWh with EV load and summary of the observations are presented in Table 8.2.7.

Table 8.2.7: Janta colony 2030 observations for Case 1

Feeder peak	
Feeder peak load (MW)	4.07
Time	23:00
EV load (kW)	134.57

Maximum EV load		
EV peak (kW)	173.92	
Time	20:15	
Feeder load (MW)	3.38	
EV peak % of feeder load	5.15%	
Energy consumption		
Energy consumption by feeder (MWh)	81.59	
Energy consumption by EV (MWh)	2.35	
% Energy consumption by EV	2.88%	
Energy supplied		
By Grid (MWh)	81.59	
By Solar PV (MWh)	-	
11kV feeder loss		
Unit	(MWh)	(%)
Case 1 (MWh)	2.205	2.70%

It is observed from Table 8.2.7 that the feeder load profile changes with the addition of EVs and adds to the existing loading in the system. 11kV feeder loading current (A) with EV and without EVs in the system is presented in Figure 8.2.9.

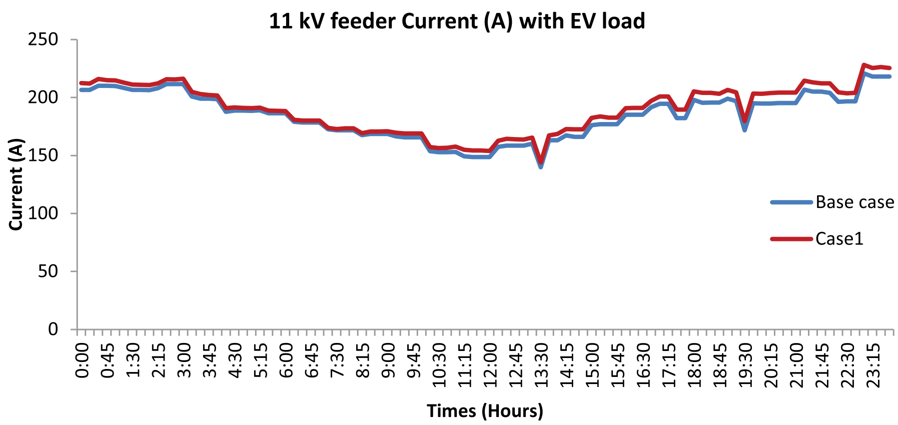


Figure 8.2.9: 11 kV feeder current profile with EV loads.

From the simulation results, it is observed that high EV penetration is there during morning and evening periods. Impact of loading on each DT varies as per the charging behaviour and connected EVS under DTs which follows random distribution. It can also be noted that, DT: JCN1_PM_630KVA and DT: JCN7_PL1_630KVA are already overloaded in the base case with loading of more than 100% and 90% respectively for certain period of time. Hence these two transformers can be considered for up gradation.

Janta colony consists of 10 distribution transformers and the loading of each transformer throughout the day with EV load in the feeder is presented from Figure 8.2.10 to Figure 8.2.14.

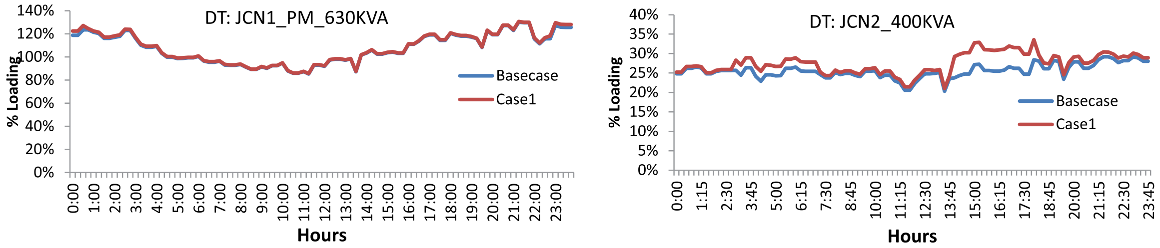


Figure 8.2.10: Transformer % loading of JCN1_PM_630KVA and JCN2_400VA

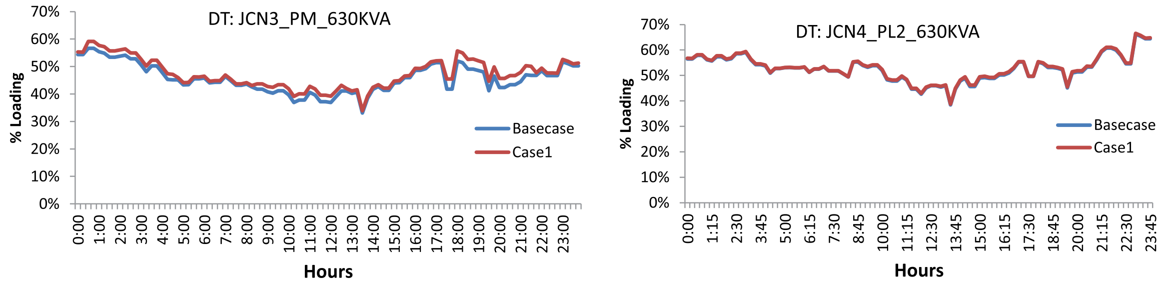


Figure 8.2.11: Transformer % loading of JCN3_PM_630KVA and JCN4_PL2_630KVA

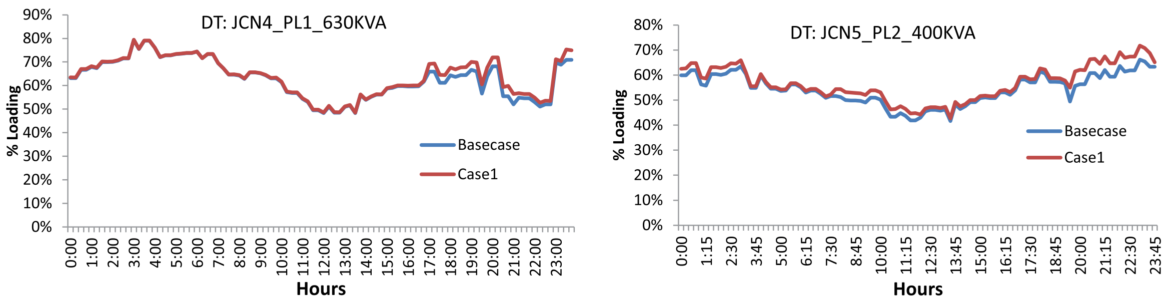


Figure 8.2.12: Transformer % loading of JCN4_PL1_630KVA and JCN5_PL2_400KVA

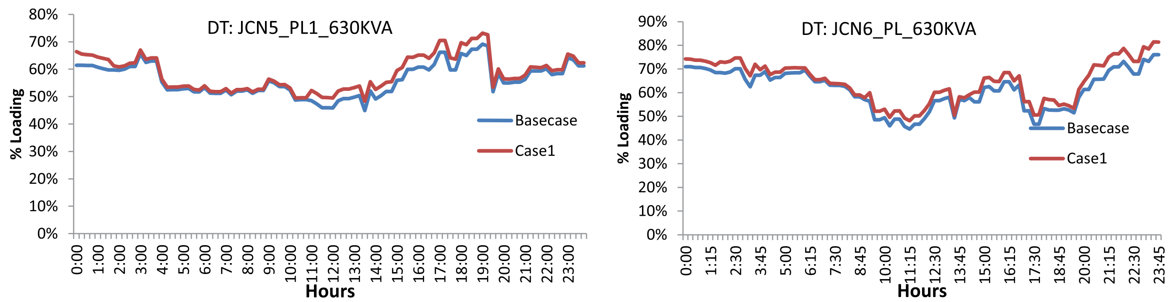


Figure 8.2.13: Transformer % loading of JCN5_PL1_630KVA and JCN6_PL_630KVA

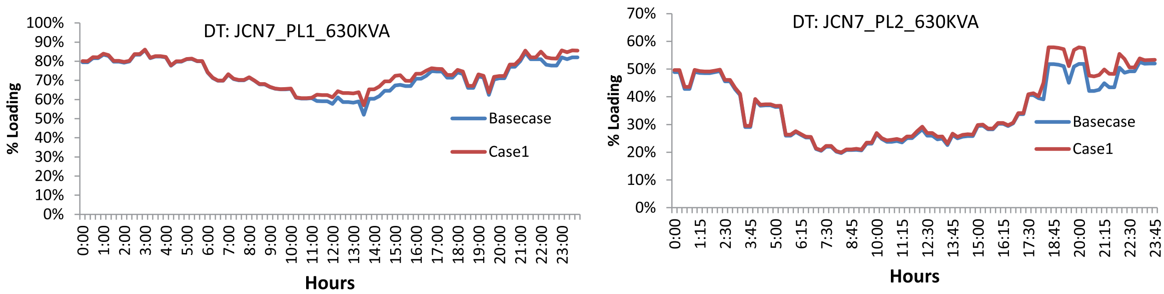


Figure 8.2.14: Transformer % loading of JCN7_PL1_630KVA and JCN7_PL2_630KVA

8.2.2.2 Case 2A: EV Penetration and Typical Solar Rooftop Generation Profile

Janta colony feeder network with EV penetration and typical solar generation is considered and simulated for a period of 24 hours. Total installed capacity of solar rooftop generation of 2.2MW is considered. Janta colony, 11 kV feeder load profile with EV loads and solar roof top generation is presented in Figure 8.2.15.

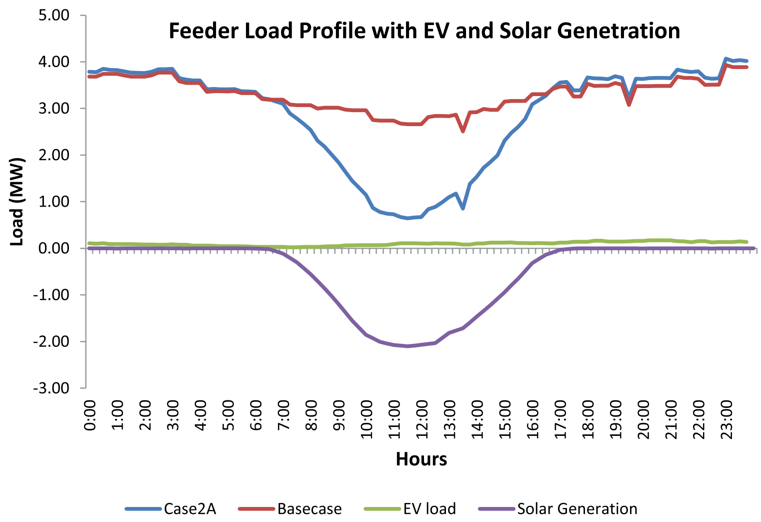


Figure 8.2.15: Janta colony feeder load profile with EV loads and solar penetration

It is observed from Figure 8.2.15 that energy drawn from the grid reduces significantly with solar generation in the feeder. Peak load of the feeder is 4.07 MW at 23:00 hours and corresponding EV load of 134.57 kW is observed. EV peak load of 173.92 kW is observed at 20:15 hours and corresponding feeder loading is 3.38MW (5.15% of feeder load).

Total energy consumed by feeder is 81.29 MWh with the contribution of 2.35 MWh by the connected EV loads, which corresponds to 2.89% of feeder daily energy consumption. Energy loss is 2.34%, 1.9 MWh with EV load and summary of the observations are presented in Table 8.2.8.

Table 8.2.8: Janta colony 2030 observations for Case 2A

Feeder peak	
Feeder peak load (MW)	4.07
Time	23:00
EV load (kW)	134.57
Maximum EV load	
EV peak (kW)	173.92
Time	20:15
Feeder load (MW)	3.38
EV peak % of feeder load	5.15%
Energy consumption	
Energy consumption by feeder (MWh)	81.29
Energy consumption by EV (MWh)	2.35
% Energy consumption by EV	2.89%

Energy supplied		
By Grid (MWh)	68.75	
By Solar PV (MWh)	**12.53**	
11kV feeder loss		
Unit	(MWh)	(%)
Case 2A (MWh)	1.904	2.34%

11kV feeder loading (A) with EV load and typical solar generation in the system is presented in Figure 8.2.16.

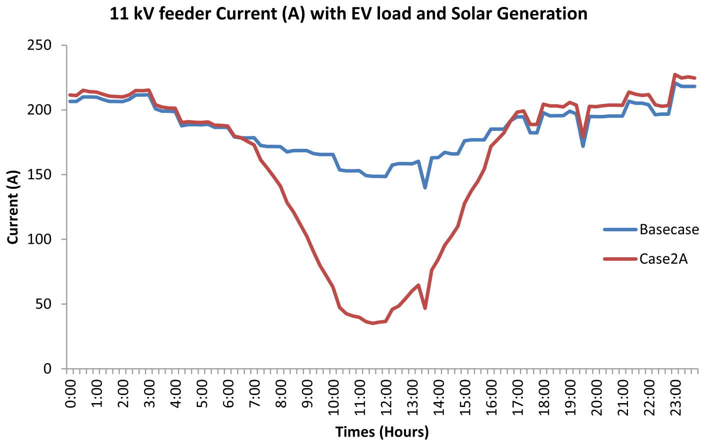


Figure 8.2.16: 11 kV feeder current profile with EV loads and typical solar generation profile

Percentage loading of selected distribution transformers with EV loads and solar generation in the feeder are presented from Figure 8.2.17 to Figure 8.2.18.

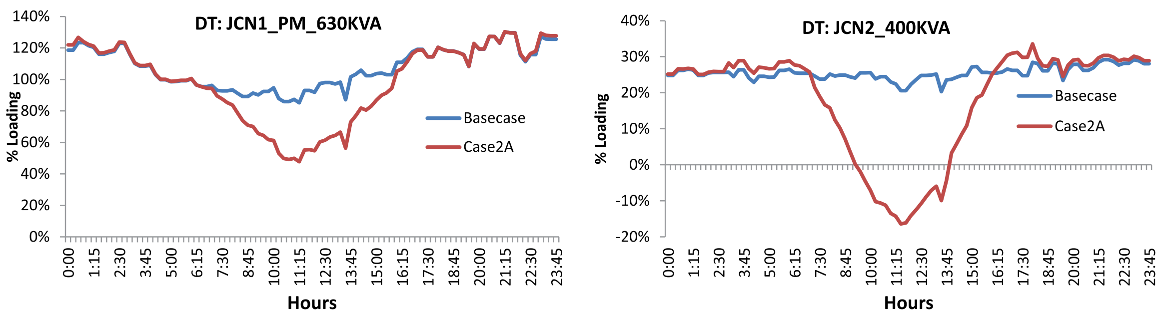


Figure 8.2.17: Transformer % loading of JCN1_PL_630KVA and JCN4_400KVA

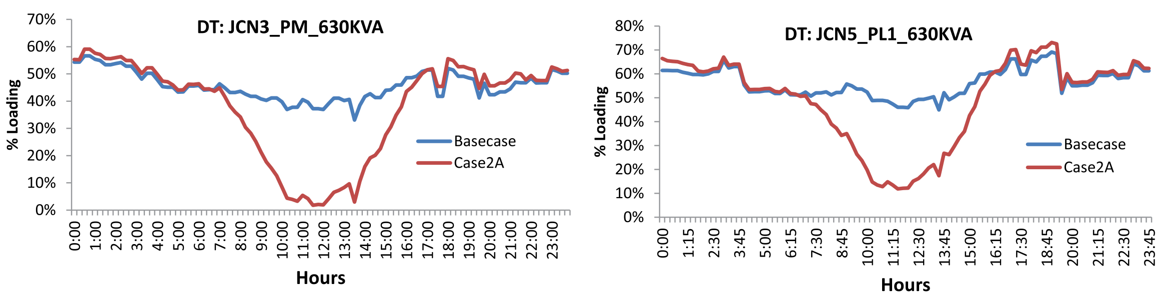


Figure 8.2.18: Transformer % loading of JCN3_PM_630KVA and JCN5_PL1_630KVA

From the simulation studies, it is observed that the impact of EV charging during PV generation is minimal or nil. Feeder can take up more EV charging during PV generation. The additional EV charging load that can be taken up during PV generation and the incentivisation of charging time slots by means of Time of Usage (ToU) tariff are presented for Arya Samaj feeder in the subsequent section.

It is also seen from Figure 8.2.18 that the loading of the DT comes down to almost 0% when PV generation reaches maximum. Any additional amount of PV generation will make the reverse power flows at DT. However, considering the Janta Colony 11 kV feeder, when PV generation is maximum at 2 MW (90% of 2.3 MW) and corresponding feeder load is around 2.6 MW; no reverse power flow is observed at 33/11 kV transformer due to diversity of PV generation thorough out the feeder. Similar diversity may be observed on other 11 kV feeders. Hence in case, DISCOM want to control the reverse power flow at 33/11 kV grid transformer, the maximum solar PV penetration can be limited to minimum loading of grid transformer with proper configuration of fuse coordination under grid transformer. This will not require any changes to protection settings to grid transformer and above network. This allows PV penetration above 40% of DT capacity under each DT and maintains no reverse power flows at grid transformer. There are several other ways by which PV roof top penetration can be increased by enhancing protection settings and maintain harmonics within the limit. DISCOM can take a call on case- to-case basis.

8.2.2.3 Case 2B: EV Penetration and Variable Solar Rooftop Profile

Janta colony feeder network with EV penetration and varying solar generation is considered and is simulated for a period of 24 hours. Total installed capacity of solar rooftop generation of 2.2 MW is considered. Janta colony 11 kV feeder load profile with EV loads and varying solar roof top generation is presented in Figure 8.2.19.

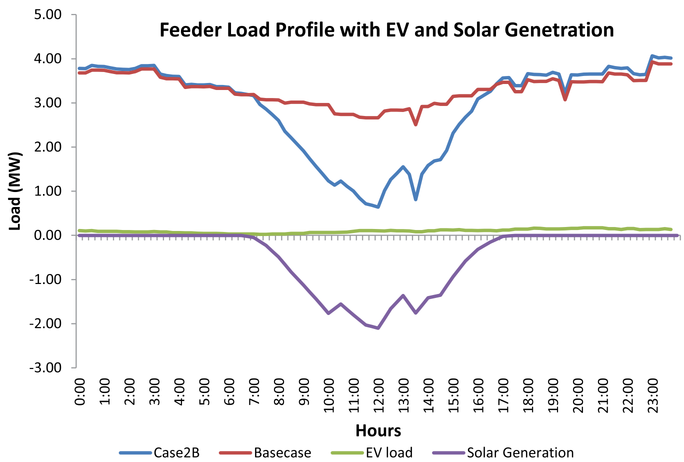


Figure 8.2.19: Janta colony feeder load profile with EV loads and solar penetration

It is observed from Figure 8.2.19 that power drawn from the grid reduces significantly with solar generation in the feeder. The pattern of power drawl from the grid reflects the rooftop solar generation pattern. Peak load of the feeder is 4.07 MW at 23:00 hours and corresponding EV load of 134.57 kW is observed. EV peak load of 173.92 kW is observed at 20:15 hours and corresponding feeder loading is 3.38MW (5.15% of feeder load).

Total energy consumed by feeder is 81.29 MWh with the contribution of 2.35 MWh by the connected EV loads, which corresponds to 2.89% of feeder daily energy consumption. Energy loss is 2.35%, 1.91 MWh with EV load and summary of the observations are presented in Table 8.2.9.

Table 8.2.9: Janta colony 2030 observations for Case 2B

Feeder peak		
Feeder peak load (MW)	4.07	
Time	23:00	
EV load (kW)	134.57	
Maximum EV load		
EV peak (kW)	173.92	
Time	20:15	
Feeder load (MW)	3.38	
EV peak % of feeder load	5.15%	
Energy consumption		
Energy consumption by feeder (MWh)	81.29	
Energy consumption by EV (MWh)	2.35	
% Energy consumption by EV	2.89%	
Energy supplied		
By Grid (MWh)	69.78	
By Solar PV (MWh)	11.51	
11kV feeder loss		
Unit	(MWh)	(%)
Case 2B (MWh)	1.913	2.35%

11kV feeder loading (A) with EV load and varying solar generation in the system is presented in Figure 8.2.20

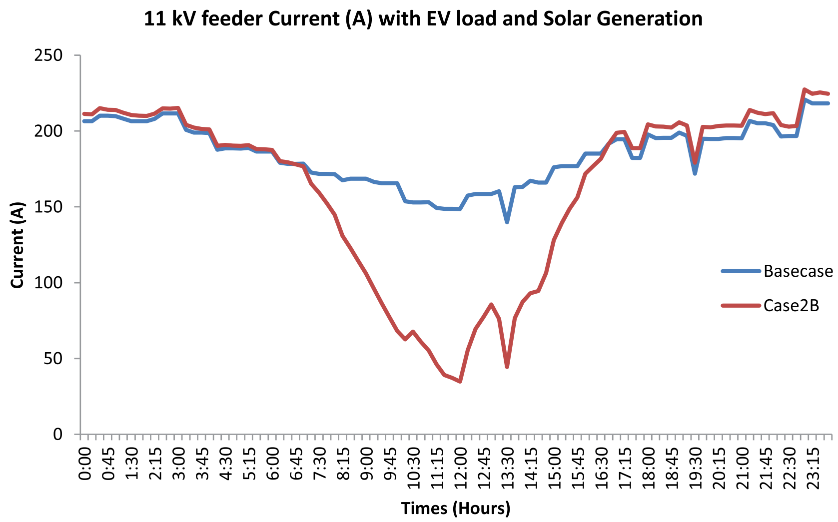


Figure 8.2.20: 11 kV feeder current profile with EV loads and varying solar generation profile

Percentage loading of distribution transformers for this case is provided in section 8.3.1 of the annexure.

8.2.2.4 Case 3: EV Penetration with Public Charging Station

According to Ministry of Power (MOP) regulations, a public charging station shall have one or more electric kiosks/boards with installation of following:

a. Fast charger – CCS connector (min 50 kW), CHAdeMO (min 50 kW), Type 2 AC (min 22 kW)

b. Slow/Moderate charger – Bharat DC-001 connector (15 kW) and Bharat AC-001 (10 kW)

Considering the regulations and standards mentioned above as on date, the number of charging points at public charging station are increased considerably to accommodate the EVs projected in the methodology .

Janta colony feeder network with public charging station is presented in Figure 8.2.21. As there are no voltage issues are observed in the feeder due to load and EV loads, Public charger is considered at the middle of the feeder. In case of voltage violations in the feeder, the optimal location of public charger is at the starting of 11 kV feeder.

11 kV feeder load profile with regular EV loads and a public charger is presented in Figure 8.2.22. No solar PV generation is considered for this case. The impact of EV penetration with public charger and solar PV generation is addressed for Arya Samaj feeder in next section.

In addition to EV's distributed across Janta colony as furnished in Table 8.2.6, vehicles distribution throughout the day for DT in public charging station is given in Table 8.2.10

Table 8.2.10: Random distribution of EVs under Public charger DT in Janta colony for 2030

Name of the DT	No of EV's	Cumulative battery capacity (kWh)
DT-Public Charging	73	1874

Figure 8.2.21: Janta colony distribution network with 1 public charger

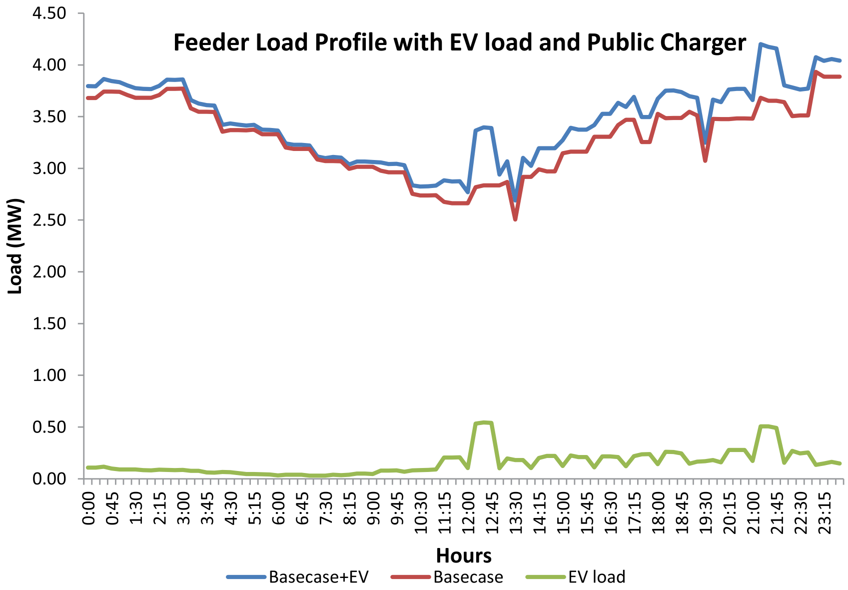


Figure 8.2.22: Janta colony feeder load profile with EV loads and a public charger

EVs considered at public charging station are plugged in for a maximum of 1 hour considering the rate of charge. EV load pattern in the beginning of a charging session rises since power drawl is high in constant current mode and the power drawl reduces when the charging switches to constant voltage mode, hence the dip in power drawl from grid.

Peak load of the feeder is 4.2 MW at 21:15 hours and corresponding EV load of 506.65 kW is observed. EV peak load of 543.96 kW is observed at 12:30 hours and corresponding feeder loading is 2.77MW (19.65% of feeder load).

Total energy consumed by feeder is 82.96 MWh with the contribution of 3.7 MWh by the connected EV loads, which corresponds to 4.46% of feeder daily energy consumption. Energy loss is 2.69%, 2.23 MWh with EV load and summary of the observations are presented in Table 8.2.11.

Table 8.2.11: Janta colony 2030 observations for Case 3

Feeder peak	
Feeder peak load (MW)	4.20
Time	21:15
EV load (kW)	506.65
Maximum EV load	
EV peak (kW)	543.96
Time	12:30
Feeder load (MW)	2.77
EV peak % of feeder load	19.65%
Energy consumption	
Energy consumption by feeder (MWh)	82.96
Energy consumption by EV (MWh)	3.70
% Energy consumption by EV	4.46%

Energy supplied		
By Grid (MWh)	82.96	
By Solar PV (MWh)	-	
11kV feeder loss		
Unit	(MWh)	(%)
Case 3 (MWh)	2.228	2.69%

11kV feeder loading (A) with EV load and a public charger in the system is presented in Figure 8.2.23.

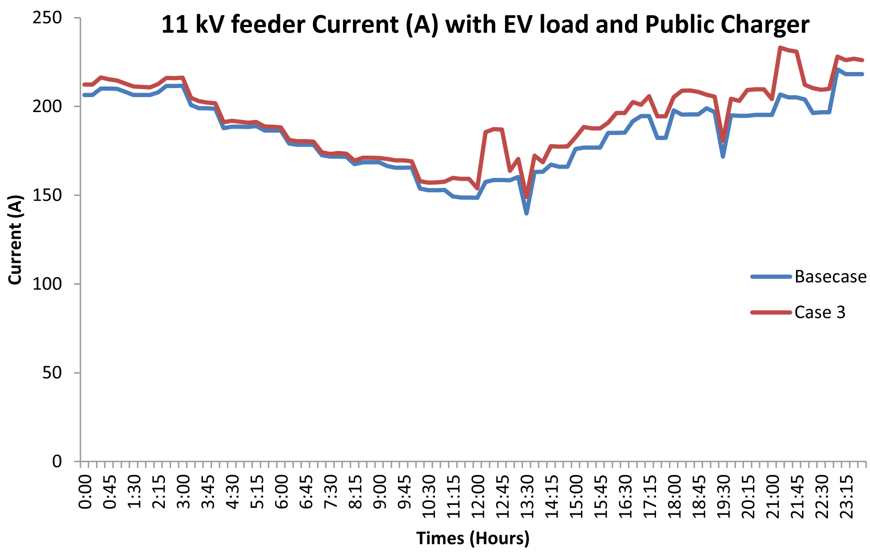


Figure 8.2.23: 11 kV feeder current profile with EV loads and a public charger

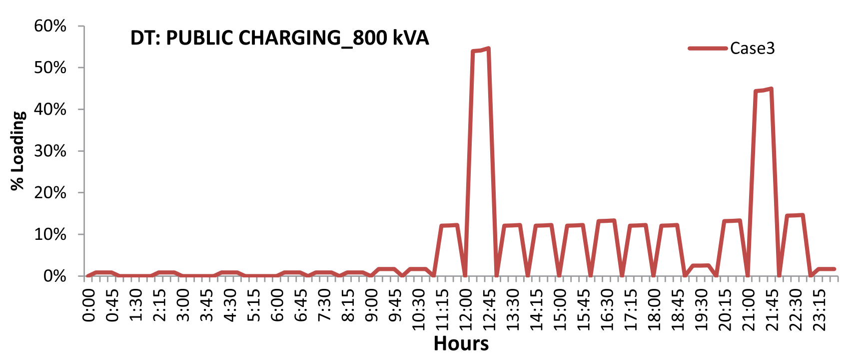


Figure 8.2.24: Transformer % loading at Public charging station

The public charging transformer loading pattern observed is presented in Figure 8.2.24. Power drawl is significantly less in the early hours of the day due to 1 or 2 vehicles are schedules for charging. As the day progresses the DT loading increases due to multiple vehicles charging at the public charging station. Since the initial SOC of 25% is considered and the vehicles are plugged in for the entire time slot in the simulation, the loading pattern of DT is obtained as in Figure 8.2.24 because EV draws more power initially in constant current mode until the SOC of the battery reaches a certain level and switches over from constant current mode to constant voltage mode where power drawl is lesser.

8.2.2.5 Summary of Results for Janta Colony

Summary of Janta colony simulation results for the year 2030 is furnished in Table 8.2.12.

Table 8.2.12: Summary of observations of Janta colony cases for 2030

Observation		Base case	Case 1	Case 2A	Case 2B	Case 3
BC		**BC+EV**	**BC+EV+PV1**	**BC+EV+PV2**	**BC+EV+PC**	
Feeder peak						
Feeder peak load	MW	3.93	4.07	4.07	4.07	4.20
Time	Hrs:min	23:00	23:00	23:00	23:00	21:15
EV load	kW	-	134.57	134.57	134.57	506.65
Maximum EV load						
EV peak	kW	-	173.92	173.92	173.92	543.96
Time	Hrs:min	-	20:15	20:15	20:15	12:30
Feeder load	MW	-	3.38	3.38	3.38	2.77
EV peak % of feeder load	%	-	5.15%	5.15%	5.15%	19.65%
Energy consumption						
Energy consumption by feeder	MWh	79.16	81.59	81.29	81.29	82.96
Energy consumption only by EV	MWh	-	2.35	2.35	2.35	3.70
% Energy by EV	%	-	2.88%	2.89%	2.89%	4.46%
Energy supplied						
By Grid	MWh	79.16	81.59	68.75	69.78	82.96
By Solar PV	MWh	-	-	12.53	11.51	-
11kV feeder loss						
Loss	MWh	2.13	2.21	1.90	1.91	2.23
% loss	%	2.68%	2.70%	2.34%	2.35%	2.69%

From the summary of the simulation results, it is observed that the increase in feeder peak load is around 135 kW when EV's with high capacity batteries penetrates in the feeder for the year 2030. The projected EV penetration has minimal impact on distribution feeder for the year 2030. In terms of energy, EVs contribute for around 4.46% and 2.88% of daily feeder energy with and without public charging station respectively in Janta colony feeder. In addition, solar rooftop generation will relieve the grid and allows while promoting the public, mall and office charging facilities by imposing Time of Usage (ToU) tariff. The losses in the feeder increased to 4.82% and 3.78% with and without public charger in the feeder. Simulations carried out for the years 2023 and 2019 are provided in Annexure part of this report. Cases simulated for the years 2019 and 2023 for Janta colony feeder is presented in section 8.3 of annexure.

8.3 MVR Sadar Feeder

MVR Sadar, 11 kV feeder emanates from 66/11 kV MAYUR VIHAR PHASE-2 substation and consists of 25 distribution transformers. MVR Sadar feeder consists of 2027 connections in total, which contributes to 0.12% of total BYPL connections. MVR Sadar feeder network is presented in Figure 8.4.3.

Total number of EVs projected for MVR Sadar feeder for future years considered from Table 7.2.3 and is shown in Figure 8.3.1

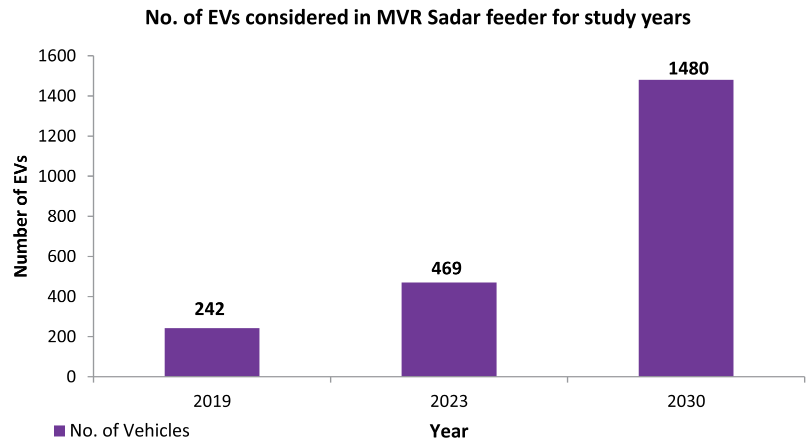


Figure 8.3.1: Total number of EVs projected for MVR Sadar feeder for future years

8.3.1 Base Case

MVR Sadar feeder network is modelled with the existing loads as per the selected load profile. Typical daily load profile for MVR Sadar feeder for the month of June is considered since Delhi peak and BYPL peak were observed in the month of June. Feeder peak of 5.64 MW is observed for MVR Sadar feeder in 2018, however at the feeder peak instant the DTs loading s to not match with the feeder peak load, hence the DT loadings are scaled up to match the feeder loading for all 15 minute intervals during the selected day. The selected load profile is shown in Figure 8.3.2.

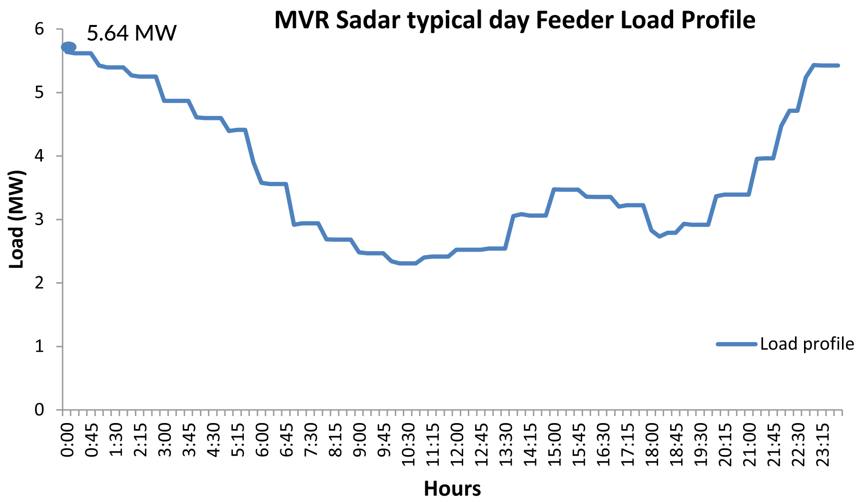


Figure 8.3.2: MVR Sadar feeder-Typical day load profile

Nomenclature for transformers in MVR Sadar feeder has been used for convenience, as presented in Table 8.3.1

Table 8.3.1: Transformer nomenclature

Transformer name	Nomenclature
TRF-1S/S-1 CHILLA COMPLEX	CHCMP_LT
TRF-1:SADAR CGHS	SRCGHSL1
TRF-2:SADAR CGHS	SRCGHSL2
TRF-1:UPKAR C.G.H.S	UPCGHSL1
TRF-2:UPKAR C.G.H.S	UPCGHSL2
TRF-1:OCF NEAR CLUB CHILLA:ID	OCFNCCL1
TRF-1:SHEKHAR C.G.H.S	SHCHGSL1
TRF-1:ARUR G.H.S.(RIVER VIEW)	ARRGHSL1
TRF-2:ARUR G.H.S.(RIVER VIEW)	ARRGHSL2
TRF-1:O.C.S C.G.H.S.	OSCGHSL1
TRF-2:O.C.S C.G.H.S.	OSCGHSL2
TRF-1:MEGHA GROUP HOUSING SOCIETY	MEGRHSL1
TRF-2:MEGHA GROUP HOUSING SOCIETY	MEGRHSL2
TRF-1:ASHIYANA S/S-1	ASYNS1L1
TRF-1:ASHIYANA S/S-2	ASYNS2L1
TRF-2:ASHIYANA S/S-2	ASYNS2L2
TRF-2:PANJABI SOUDHAGAR	PNJSODL1
TRF-1:PANJABI SOUDHAGAR	PNJSODL2
TRF-1:DRONACHARIA S/S-2	DRNCS1L2
TRF-1:DRONACHARIA S/S-1	DRNCS2L1
TRF-2:DRONACHARIA S/S-1	DRNCS2L2

Sanctioned loads are modelled at each pole and scaled to match phase imbalance and DT loading for every 15 minutes interval as per the available feeder loading. Transformer loading in base case is presented in Table 8.3.2.

Table 8.3.2: MVR Sadar transformer loading in base case

Transformer name	Transformer Capacity (MVA)	Transformer loading at feeder peak (MW)	Simulated results of transformer loading (MW)	Error %
CHCMP_LT	0.4	0.246	0.249	1.12%
SRCGHSL1	0.63	0.289	0.303	5.12%
SRCGHSL2	0.63	0.217	0.209	3.34%
UPCGHSL1	0.63	0.440	0.451	2.43%
UPCGHSL2	0.63	0.354	0.363	2.32%
OCFNCCL1	0.63	0.134	0.134	0.32%
SHCHGSL1	0.63	0.257	0.262	2.06%
ARRGHSL1	0.63	0.255	0.263	3.06%
ARRGHSL2	0.63	0.166	0.168	1.21%
OSCGHSL1	0.63	0.273	0.275	0.54%

OSCGHSL2	0.63	0.420	0.426	1.36%
MEGRHSL1	0.63	0.383	0.389	1.64%
MEGRHSL2	0.63	0.377	0.383	1.55%
ASYNS1L1	0.63	0.282	0.286	1.27%
ASYNS2L1	0.63	0.243	0.245	1.08%
ASYNS2L2	0.63	0.196	0.198	1.34%
PNJSODL1	0.63	0.204	0.206	0.97%
PNJSODL2	0.63	0.158	0.158	0.31%
DRNCS1L2	0.4	0.077	0.078	0.60%
DRNCS2L1	0.4	0.205	0.207	1.02%
DRNCS2L2	0.4	0.464	0.481	3.48%

8.3.2 Simulation Studies for the Year 2030

Considering the advancement in battery technology and current EV trends in European countries, for the year 2030, higher battery sizes of EVs are considered. With higher EV battery capacity it is natural that the ranges of the EVs are higher which means frequency of charging the EV is lesser. Considering the fact that the average daily distance commuted by all the vehicle categories will be same in the future, total number of charges per vehicle per year with 25% initial SOC is calculated. Higher battery capacities considered as per current trends in European countries and their corresponding number of charges per year is presented in Table 8.3.3.

Table 8.3.3: EV Battery capacities considered for year 2030

Vehicle Category	Battery Capacity (kWh)	No. of charges per year per vehicle
2W	4	65
3W - PV	7	487
3W - CV	9	389
4W - PV	80	48
4W - CV	80	292
Bus	250	389

Cases considered for MVR Sadar feeder for year 2030 is presented in Figure 8.3.3.

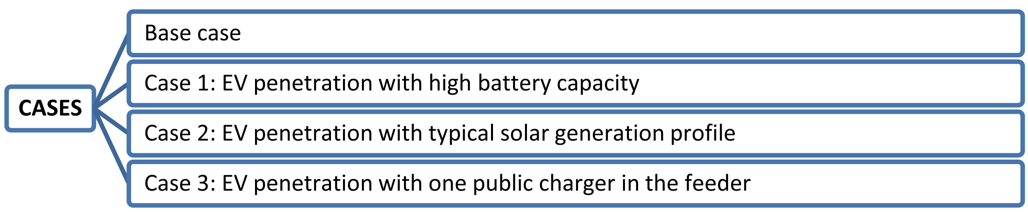


Figure 8.3.3: Cases considered for MVR Sadar feeder for year 2030

8.3.2.1 Case 1: EV penetration

Total EV considered in 2030 in MVR Sadar feeder and total charges is presented in Figure 8.3.4 and Distribution of charging of each vehicle category at different charging locations is furnished in Figure 8.3.4

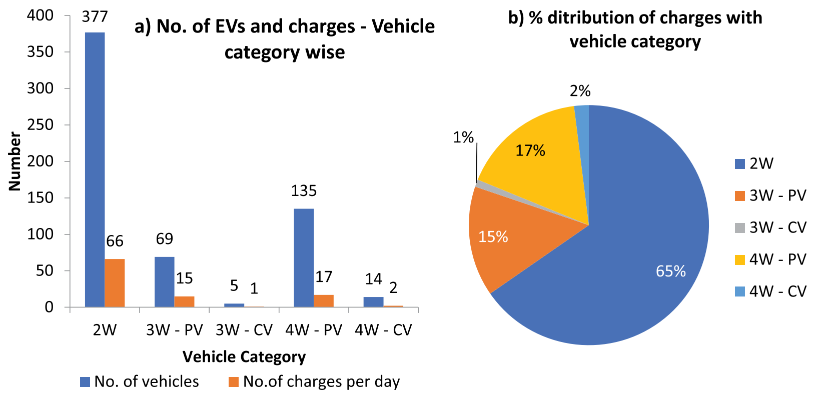


Figure 8.3.4: a) No. of EVs and charges - Vehicle category wise b) % distribution of EVs

Total number of EV charges per day considered in MVR Sadar feeder for 2030 is furnished in Table 8.3.4.

Table 8.3.4: Total EV charges per day considered in MVR Sadar feeder for 2030

Vehicle category	Home charging	Office/Work charging	Mall/ Parking charging
2W	44	21	1
3W - PV	13	-	2
3W - CV	1	-	-
4W - PV	11	6	-
4W - CV	2	-	-
Bus	-	-	-

Total number of EV charges considered per day for different vehicle categories are distributed throughout the day in different time slots, from TS1 to TS24. EVs are plugged in at different poles under different DTs randomly. The random distribution has been selected as EV penetration under each DT will not follow uniform distribution in the future times. Random distribution of EVs for each DT in MVR Sadar feeder throughout the day for different time slots is presented in Table 8.3.5.

Table 8.3.5: Random distribution of EVs for each DT in MVR Sadar for 2030

Random distribution of EVs under each DT		
Name of the DT	**No. of EVs plugged in a day**	**Cumulative battery capacity (kWh)**
CHCMP_LT	4	21
SRCGHSL1	5	101
SRCGHSL2	0	0
UPCGHSL1	4	102
UPCGHSL2	1	4
OCFNCCL1	4	16
SHCHGSL1	7	104
ARRGHSL1	2	13
ARRGHSL2	10	131

OSCGHSL1	4	92
OSCGHSL2	13	209
MEGRHSL1	2	89
MEGRHSL2	7	195
ASYNS1L1	1	4
ASYNS2L1	1	80
ASYNS2L2	0	0
PNJSODL2	9	112
PNJSODL1	8	265
DRNCS1L2	8	184
DRNCS2L1	5	106
DRNCS2L2	5	96
Total		**1924**

Case study is executed for a period of 24 hours with the selected load profile including the EV loads plugged in at different point of times in a day. MVR Sadar 11 kV feeder load profile with EV loads is presented in Figure 8.3.5

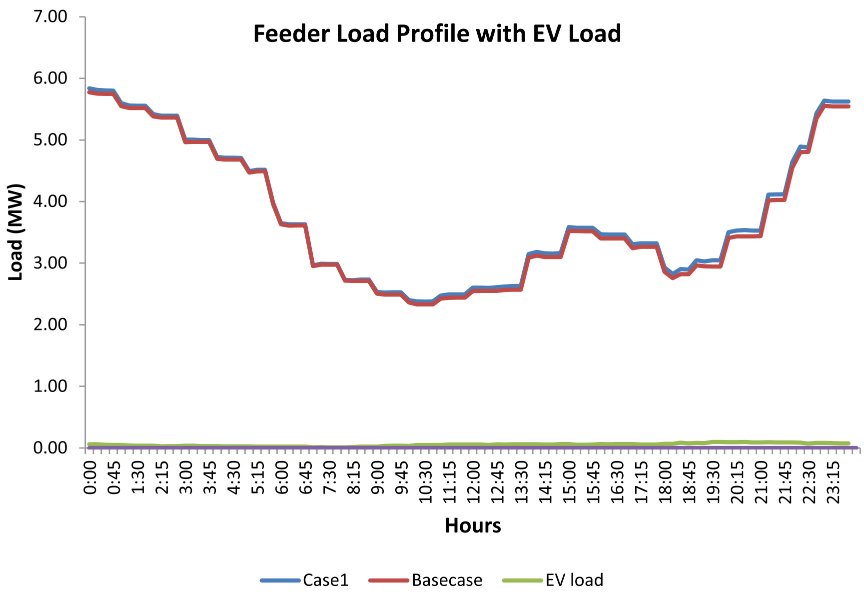


Figure 8.3.5: MVR Sadar feeder load profile with EV loads

Peak load of the feeder is 5.84 MW at 00:00 hours and corresponding EV load of 60.2 kW is observed. EV peak load of 99.65 kW is observed at 20:30 hours and corresponding feeder loading is 3.39MW (2.94% of feeder load).

Total energy consumed by feeder is 90.52 MWh with the contribution of 1.26 MWh by the connected EV loads, which corresponds to 1.39% of feeder daily energy consumption. Energy loss is 1.58%, 1.43 MWh with EV load and summary of the observations are presented in Table 8.3.6.

Table 8.3.6: MVR Sadar 2030 observations for Case 1

Feeder peak		
Feeder peak load (MW)	5.84	
Time	0:00	
EV load (kW)	60.20	
Maximum EV load		
EV peak (kW)	99.65	
Time	20:30	
Feeder load (MW)	3.393	
EV peak % of feeder load	2.94%	
Energy consumption		
Energy consumption by feeder (MWh)	90.52	
Energy consumption by EV (MWh)	1.26	
% Energy consumption by EV	1.39%	
Energy supplied		
By Grid (MWh)	90.52	
By Solar PV (MWh)	-	
11kV feeder loss		
Unit	(MWh)	(%)
Case 1 (MWh)	1.426	1.58%

It is observed from Table 8.3.6 that the feeder load profile changes with the addition of EVs and adds to the existing loading in the system. 11kV feeder loading current (A) with EV and without EVs in the system is presented in Figure 8.3.6.

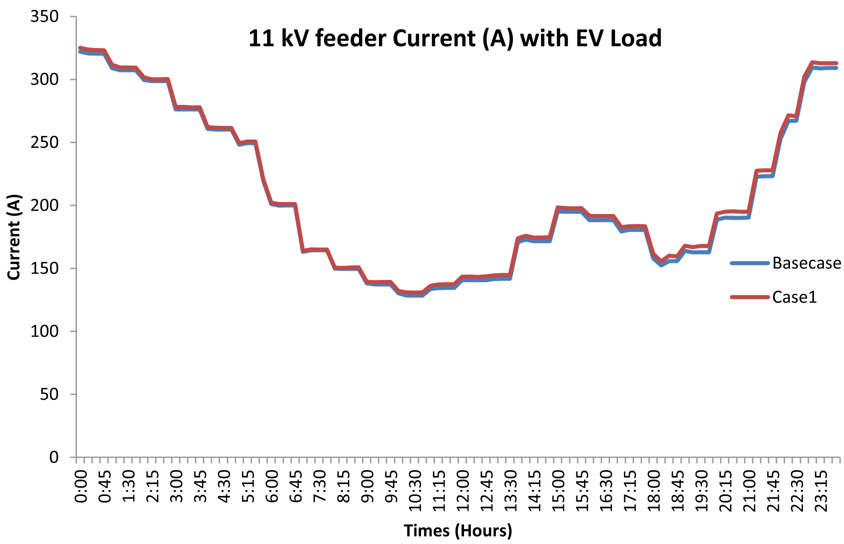
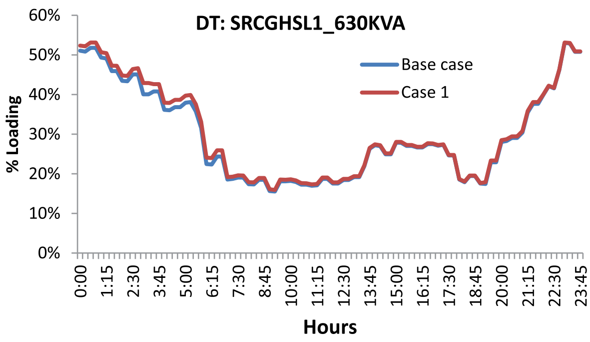


Figure 5.3.6: 11 kV feeder current profile with EV loads

MVR Sadar consists of 25 distribution transformers (out of which 21 transformers are loaded) and the loading of sample transformers throughout the day with EV load in the feeder is presented from Figure 8.3.7 and Figure 8.3.8.



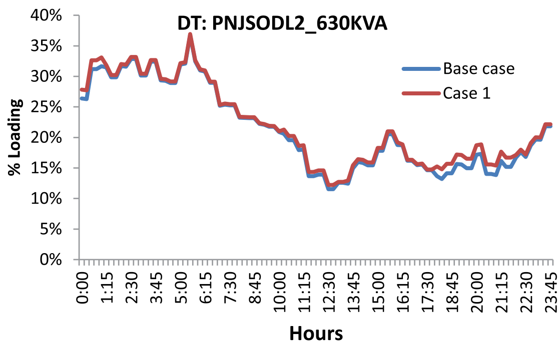


Figure 8.3.7: Transformer % loading of SRCGHSL1_630kVA and PNJSODL2_630kVA

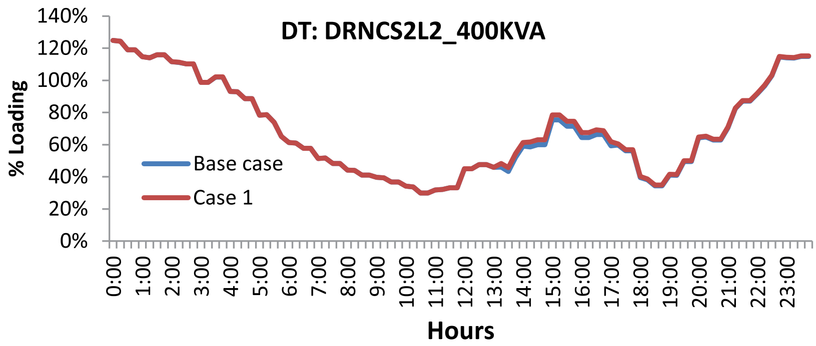


Figure 8.3.8: Transformer % loading of DRNCS2L2_400kVA

8.3.2.2 Case 2: EV penetration and typical solar rooftop generation profile

MVR Sadar feeder network with EV penetration and typical solar generation is considered and simulated for a period of 24 hours. Total installed capacity of solar rooftop generation of 572 kW is considered. MVR Sadar, 11 kV feeder load profile with EV loads and solar rooftop generation is presented in Figure 8.3.9

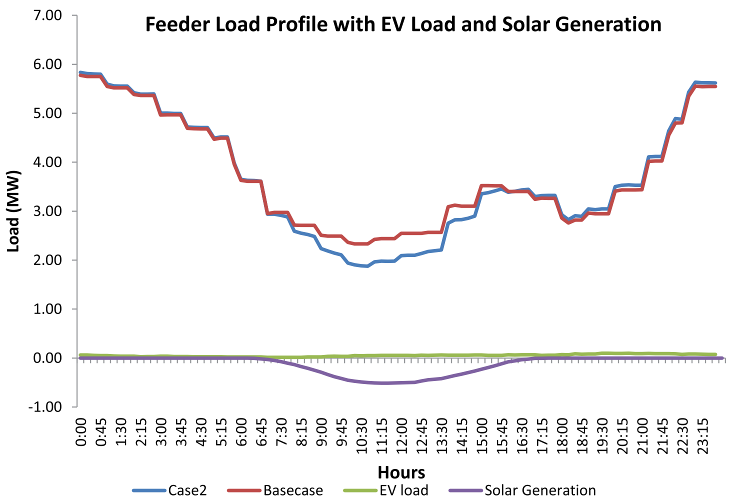


Figure 8.3.9: MVR Sadar feeder load profile with EV loads and solar penetration

It is observed from that energy drawn from the grid reduces significantly with solar generation in the feeder.

Peak load of the feeder is 5.84 MW at 00:00 hours and corresponding EV load of 60.2 kW is observed. EV peak load of 99.65 kW is observed at 20:30 hours and corresponding feeder loading is 3.39MW (2.94% of feeder load).

Total energy consumed by feeder is 90.5 MWh with the contribution of 1.26 MWh by the connected EV loads, which corresponds to 1.39% of feeder daily energy consumption. Energy loss is 1.54%, 1.4 MWh with EV load and summary of the observations are presented in Table 8.3.7.

Table 8.3.7: MVR Sadar 2030 observations for Case 2

Feeder peak		
Feeder peak load (MW)	5.84	
Time	0:00	
EV load (kW)	60.20	
Maximum EV load		
EV peak (kW)	99.65	
Time	20:30	
Feeder load (MW)	3.393	
EV peak % of feeder load	2.94%	
Energy consumption		
Energy consumption by feeder (MWh)	90.50	
Energy consumption by EV (MWh)	1.26	
% Energy consumption by EV	1.39%	
Energy supplied		
By Grid (MWh)	87.43	
By Solar PV (MWh)	3.07	
11kV feeder loss		
Unit	(MWh)	(%)
Case 2 (MWh)	1.398	1.54%

11kV feeder loading (A) with EV load and typical solar generation in the system is presented in Figure 8.1.16.

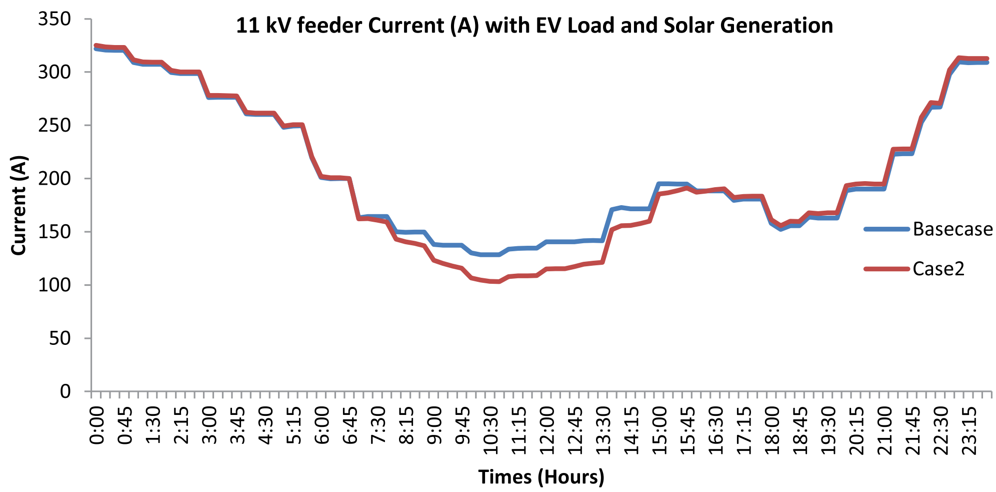


Figure 8.3.10: 11 kV feeder current profile with EV loads and typical solar generation profile

8.3.2.3 Case 3: EV penetration with public charger

11 kV feeder with regular EV loads and a public charger is presented in Figure 8.3.11. No solar PV generation is considered for this case.

Figure 8.3.11: MVR Sadar distribution network with 1 public charger

MVR Sadar 11 kV feeder load profile with EV loads is presented in Figure 8.3.12.

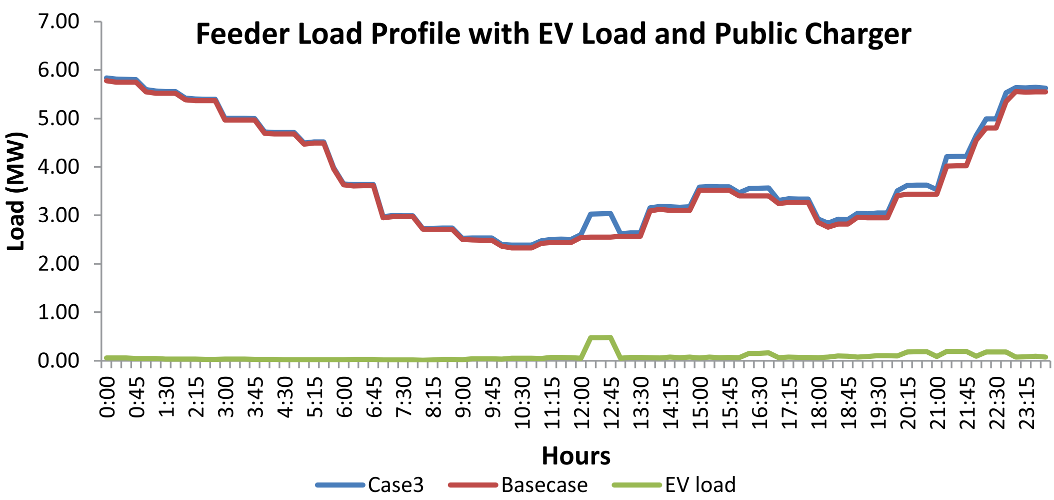


Figure 8.3.12: MVR Sadar feeder load profile with EV loads and a public charger

EVs considered at public charging station are plugged in for a maximum of 1 hour considering the rate of charge. EV load pattern in the beginning of a charging session rises since power drawl is high in constant current mode and the power drawl reduces when the charging switches to constant voltage mode, hence the dip in power drawl from grid.

Peak load of the feeder is 5.84 MW at 00:00 hours and corresponding EV load of 59.63 kW is observed. EV peak load of 479.35 kW is observed at 12:45 hours and corresponding feeder loading is 2.52MW (18.99% of feeder load).

Total energy consumed by feeder is 91.23 MWh with the contribution of 1.96 MWh by the connected EV loads, which corresponds to 2.14% of feeder daily energy consumption. Energy loss is 1.57%, 1.43 MWh with EV load and summary of the observations are presented in Table 8.3.8.

Table 8.3.8: MVR Sadar 2030 observations for Case 3

Feeder peak		
Feeder peak load (MW)	5.84	
Time	0:00	
EV load (kW)	59.63	
Maximum EV load		
EV peak (kW)	479.35	
Time	12:45	
Feeder load (MW)	2.524	
EV peak % of feeder load	18.99%	
Energy consumption		
Energy consumption by feeder (MWh)	91.23	
Energy consumption by EV (MWh)	1.96	
% Energy consumption by EV	2.14%	
Energy supplied		
By Grid (MWh)	91.23	
By Solar PV (MWh)	-	
11kV feeder loss		
Unit	(MWh)	(%)
Case 3 (MWh)	1.434	1.57%

11kV feeder loading (A) with EV load and a public charger in the system is presented in Figure 8.3.13.

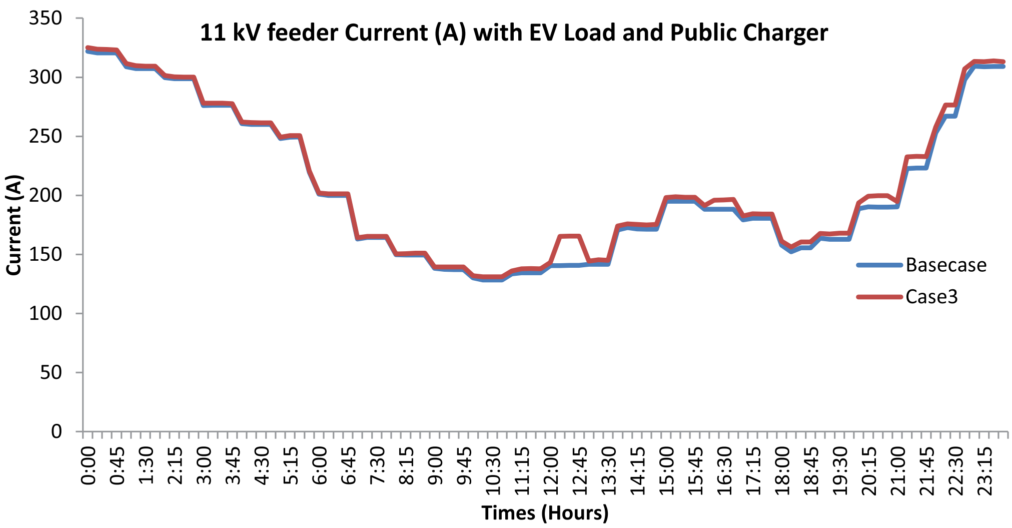


Figure 8.3.13: 11 kV feeder current profile with EV loads and a public charger

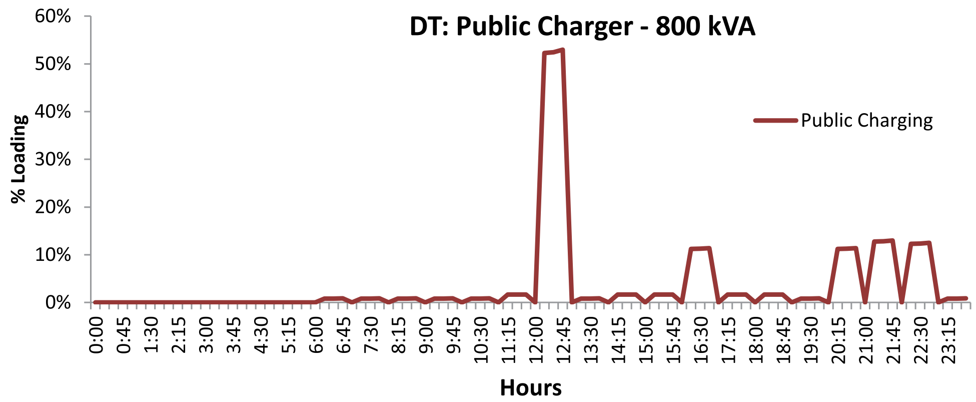


Figure 8.3.14: Transformer % loading at Public charging station

The public charging transformer loading pattern observed is presented in Figure 8.3.14. Power drawl is significantly less in the early hours of the day due to 1 or 2 vehicles are scheduled for charging. As the day progresses the DT loading increases due to multiple vehicles charging at the public charging station. Since the initial SOC of 25% is considered and the vehicles are plugged in for the entire time slot in the simulation, the loading pattern of DT is obtained as in Figure 8.3.14 because EV draws more power initially in constant current mode until the SOC of the battery reaches a certain level and switches over from constant current mode to constant voltage mode where power drawl is lesser.

Simulations for the year 2023 and 2019 are performed and results were observed to have very minimal impact on the feeder. Hence the results are not included in the report.

8.3.2.4 Summary of Simulation Results for MVR Sadar

Summary of MVR Sadar simulation results for the year 2030 is furnished in Table 8.2.12.

Table 8.3.9: Summary of observations of MVR Sadar cases for 2030

Observation		Base case	Case 1	Case 2	Case 3
BC		BC+EV	BC+EV+PV1	BC+EV+PC	
Feeder peak					
Feeder peak load	MW	5.77	5.84	5.84	5.84
Time	Hrs:min	0:00	0:00	0:00	0:00
EV load	kW	-	60.20	60.20	59.63
Maximum EV load					
EV peak	kW	-	99.65	99.65	479.35
Time	Hrs:min	-	20:30	20:30	12:45
Feeder load	MW	-	3.39	3.39	2.52
EV peak % of feeder load	%	-	2.94%	2.94%	18.99%
Energy consumption					
Energy consumption by feeder	MWh	89.25	90.52	90.50	91.23

Energy consumption only by EV	MWh	-	1.26	1.26	1.96
% Energy by EV	%	-	1.39%	1.39%	2.14%
Energy supplied					
By Grid	MWh	89.25	90.52	87.43	91.23
By Solar PV	MWh	-	-	3.07	-
11kV feeder loss					
Loss	MWh	1.40	1.43	1.40	1.43
% Loss	%	1.57%	1.58%	1.54%	1.57%

From the summary of the simulation results, it is observed that the increase in feeder peak load is around 99 kW and 479 kW with and without public charging station respectively, when EV's with high capacity batteries penetrates in the feeder for the year 2030. The projected EV penetration has minimal impact on distribution feeder for the year 2030. In terms of energy, EVs contribute for around 2.14% and 1.39% of daily feeder energy with and without public charging station respectively in MVR Sadar feeder. In addition, solar rooftop generation will relieve the grid and allows while promoting the public, mall and office charging facilities by imposing Time of Usage (ToU) tariff. The losses in the feeder increased to 2.28% and 1.69% with and without public charger in the feeder respectively.

8.4 Dedicated Feeder

A dedicated 11kV feeder emanating from 33/11 kV grid substation feeds the EV charging stations installed at the bus depot.

The EV charging stations installed at the bus depot has combination of DC fast chargers and DC slow chargers. Total EV charger capacities in the bus depot are as follows:

- 10 DC fast chargers of 250kW capacity each (utilized between 6AM to 9PM)
- 100 DC slow chargers of 50kW capacity (utilized between 9PM to 6AM)

Total installed capacity of EV charging stations of bus depot is 7.5 MW. The breakup of installed capacity for DC fast charger and DC slow charger is as follows

- DC Fast chargers[1] : 10x250 kW=2.5 MW
- DC slow chargers[2] :100x50 kW= 5 MW

The chargers are modeled with constant current characteristics. Considering that DC slow chargers may be utilized when fast chargers are plugged-in or vice versa, a deviation of 10% in maximum total demand (5 MW) available at the EV station is considered. Hence the dedicated feeder should be able to provide a maximum load of 5.5 MW at any given point of time.

Transformer:

✓ To supply maximum power of 5.5MW, 5 units of 1.25MVA each of 11/0.433kV transformers are considered.

✓ Each 11/0.415 kV, 1.25 MVA transformer supplies 2 DC fast charging stations of 250kW each and 20 DC slow charging stations of 50kW each.

1 DC charger Manufacturer- AeroVironment™ EV Solutions™, Model- EV-250FS

2 DC charger Manufacturer- AeroVironment™ EV Solutions™, Model- EV-50PS

- ✓ Considering 1 MW peak load at each transformer, consisting of 20 DC slow charging stations acting at the same time, 1.25MVA transformer is selected.

Note: It is to be noted that when there is a supply interruption and the power is back on, the 11 kV feeder will be loaded with all the EV chargers at the same time (assuming all the chargers are plugged-in to the electric buses).

Current observed in 11kV dedicated feeder:

Case 1: With all the 10 DC fast charging stations plugged in between 6 AM to 9 PM:

In this case the total connected EV charging station to the feeder is 2.75MW considering 10% deviation. For 250 kW DC fast charger, maximum input current according to manufacturer data sheet is 330 Amp at 480 V. However, for Indian scenario considering 415 V, delivering the same amount of power, the maximum current that would be drawn by a single 250 kW DC fast charger is around 382 Amps at the 415V side of the 11/0.415 kV transformer. Scenario is simulated where all 10 DC fast chargers are plugged in. In this case, it is observed that a current of **158 A** flows in the 11 kV dedicated feeder. MW flow and current flow in the feeder are presented in Figure 8.4.1 and Figure 8.4.2 respectively. The 10% deviation in total load is modeled at 11 kV bus at the bus depot.

Case 2: With all the 100 DC fast charging stations plugged in between 9 PM to 6 AM:

In this case the total connected EV charging station to the feeder is 5.5 MW considering 10% deviation. For 50 kW DC slow charger the maximum input current according to manufacturer data sheet is 68 Amp[3] at 480 V. However, for Indian scenario considering 415 V, delivering the same amount of power, the maximum current that would be drawn by a single 50 kW DC slow charger is around 79 Amps at the 415V side of the 11/0.415 kV transformer. Scenario is simulated where all 100 DC slow chargers are plugged in. In this case, it is observed that a current of **314 A flows** in the 11 kV dedicated feeder. MW flow and current flow in the feeder are presented in Figure 8.4.3 and Figure 8.4.4 respectively. The 10% deviation in total load is modeled at 11 kV bus at the bus depot.

Summary:

- ✓ For case-2 configuration, when supplying the maximum load of 5.5MW, a current of 314 Amp is observed in the feeder. The 11 kV feeder has to be selected such that it can carry at least 314 Amps under normal operation.
- ✓ Existing 3CX300sqmm, 11 kV cable utilized in the BYPL network has the current carrying capacity of 360Amps (as per data sheet provided), which is sufficient to carry the maximum current of 314 Amp as seen in case 2. Therefore, the existing 3CX300sqmm can be used for the dedicated EV feeder. However if the cable de-rated capacity when laid under the ground is lower than this, higher capacity cable to be selected as per the manufacturer provided date.

Note: Redundancy of the transformers and 11kV cables to be taken care for 2km cable and 25 mVA transformer to improve the reliability of power supply.

3 DC charger Manufacturer- AeroVironment™ EV Solutions™, Model- EV-50PS

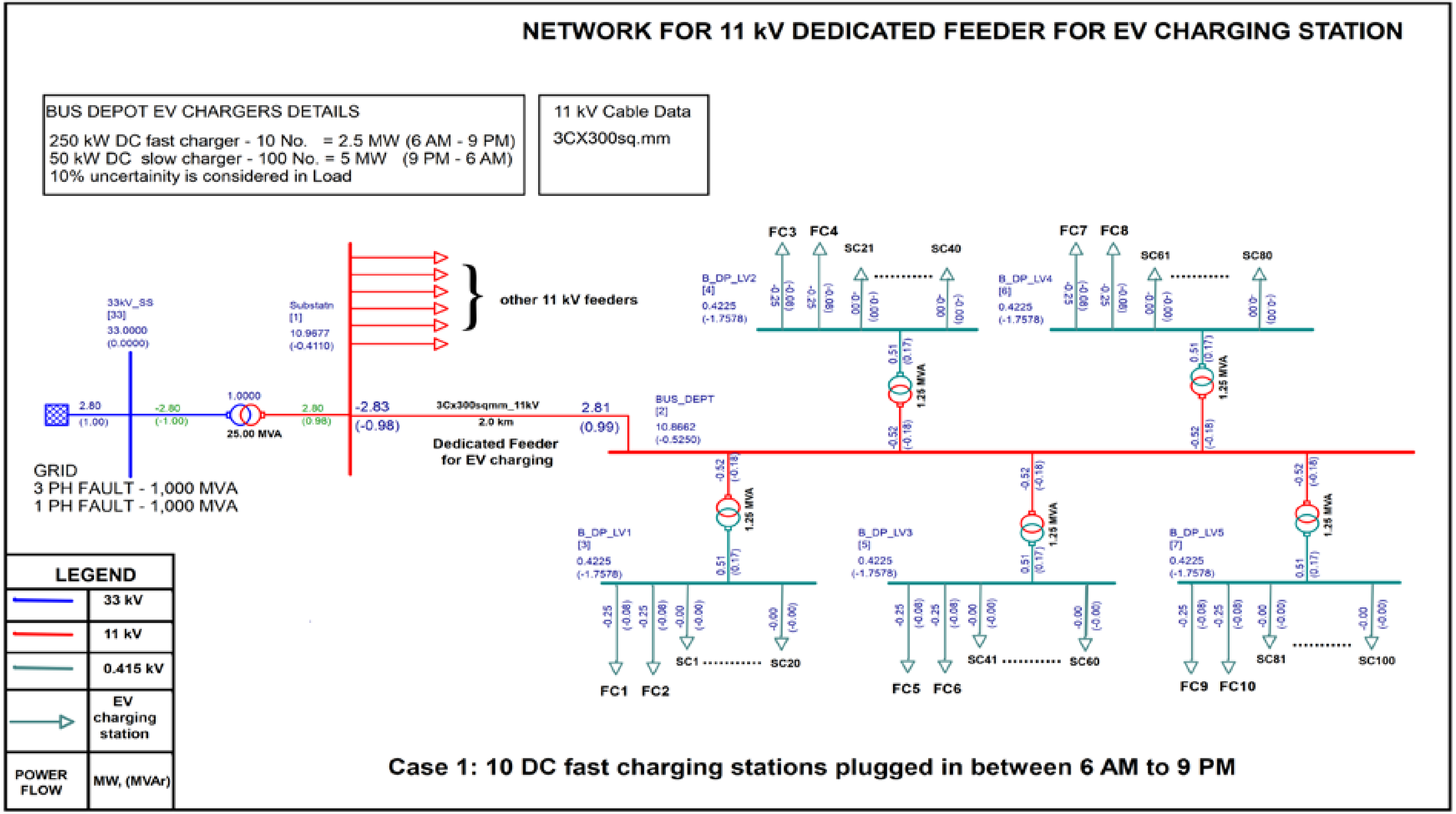


Figure 8.4.1: Power flow in dedicated feeder for EV charging stations at bus depot for Case-1

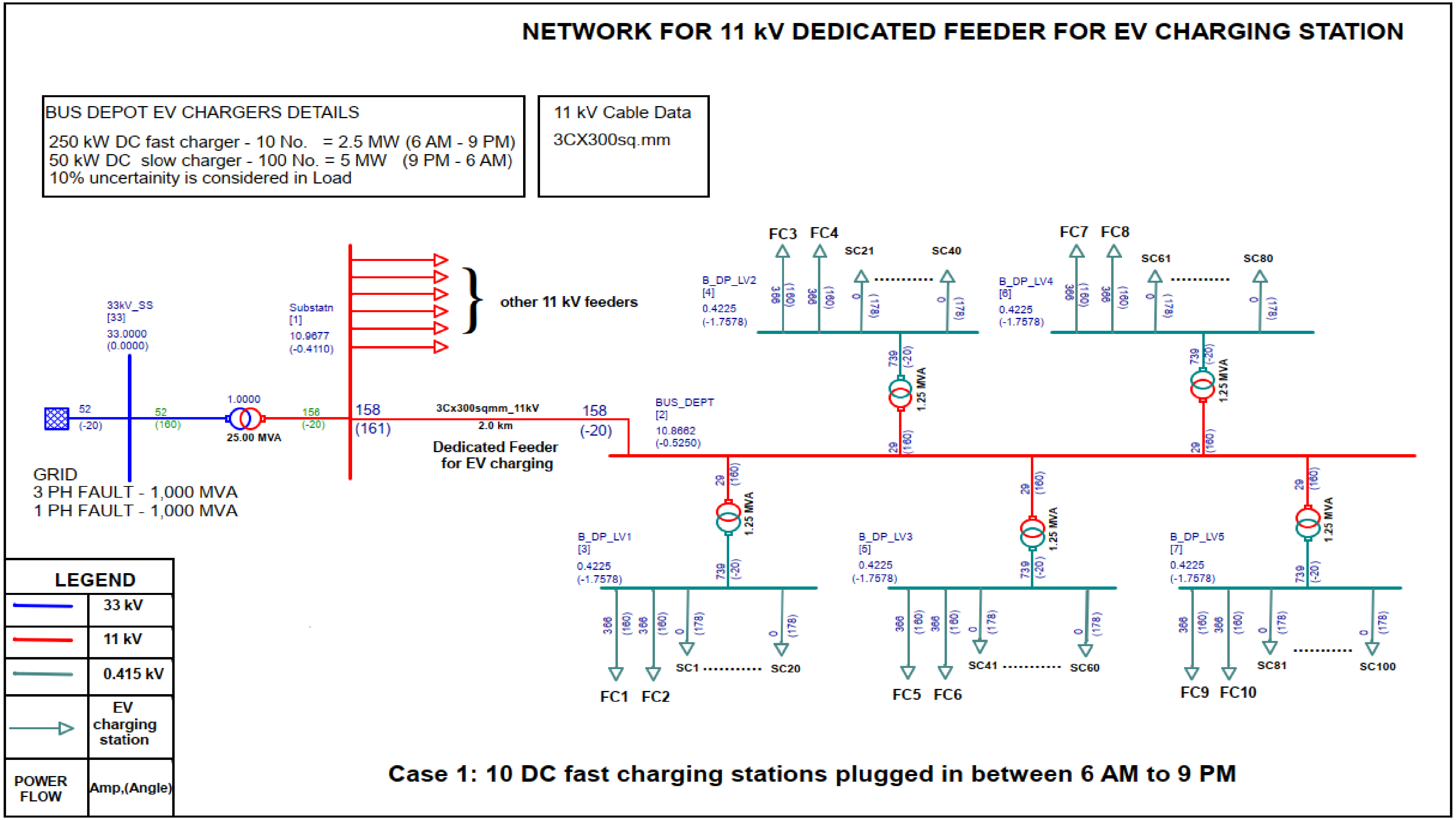


Figure 8.4.2: Current flow in dedicated feeder for EV charging stations at bus depot for Case-1

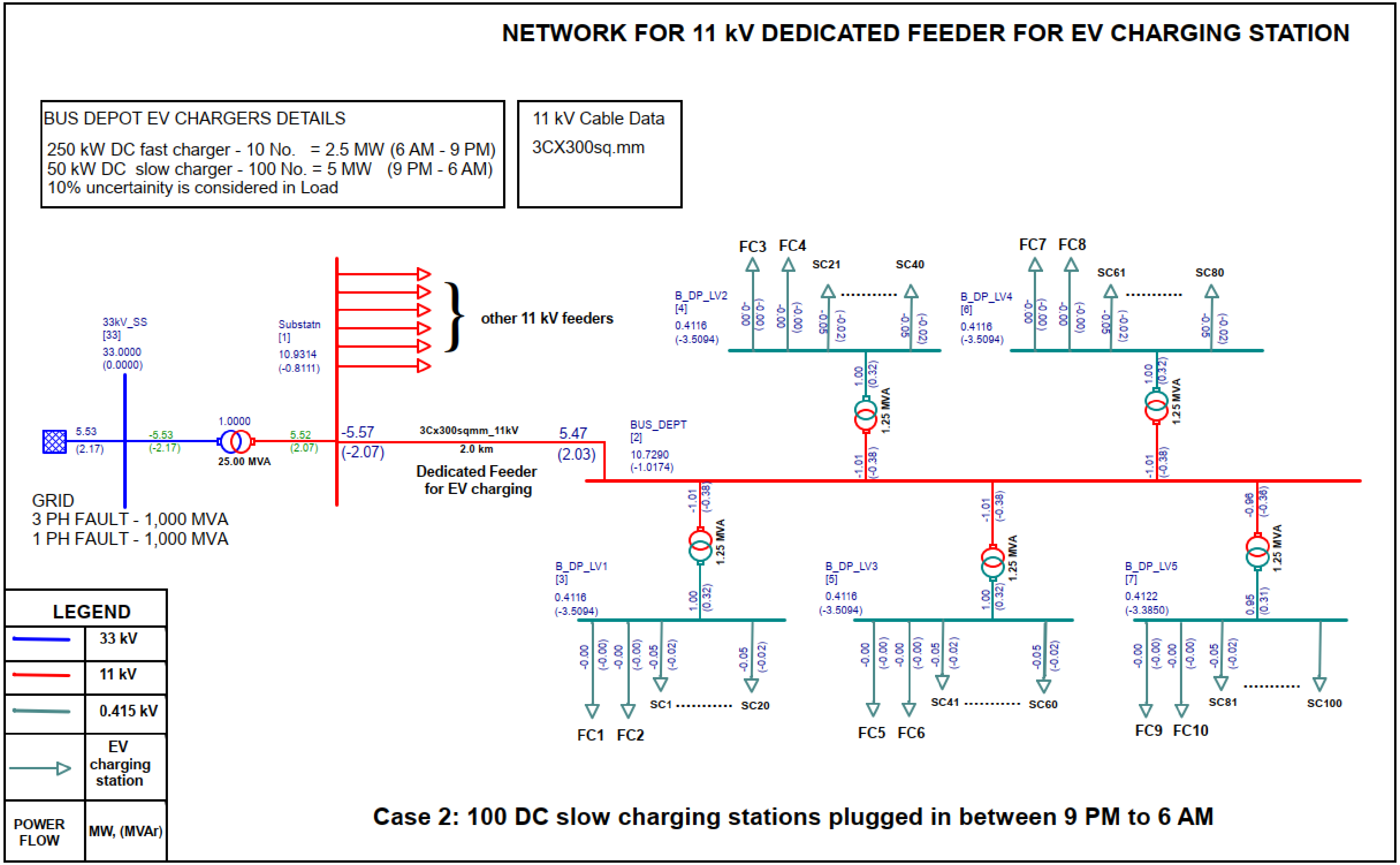


Figure 8.4.3: Power flow in dedicated feeder for EV charging stations at bus depot for Case-2

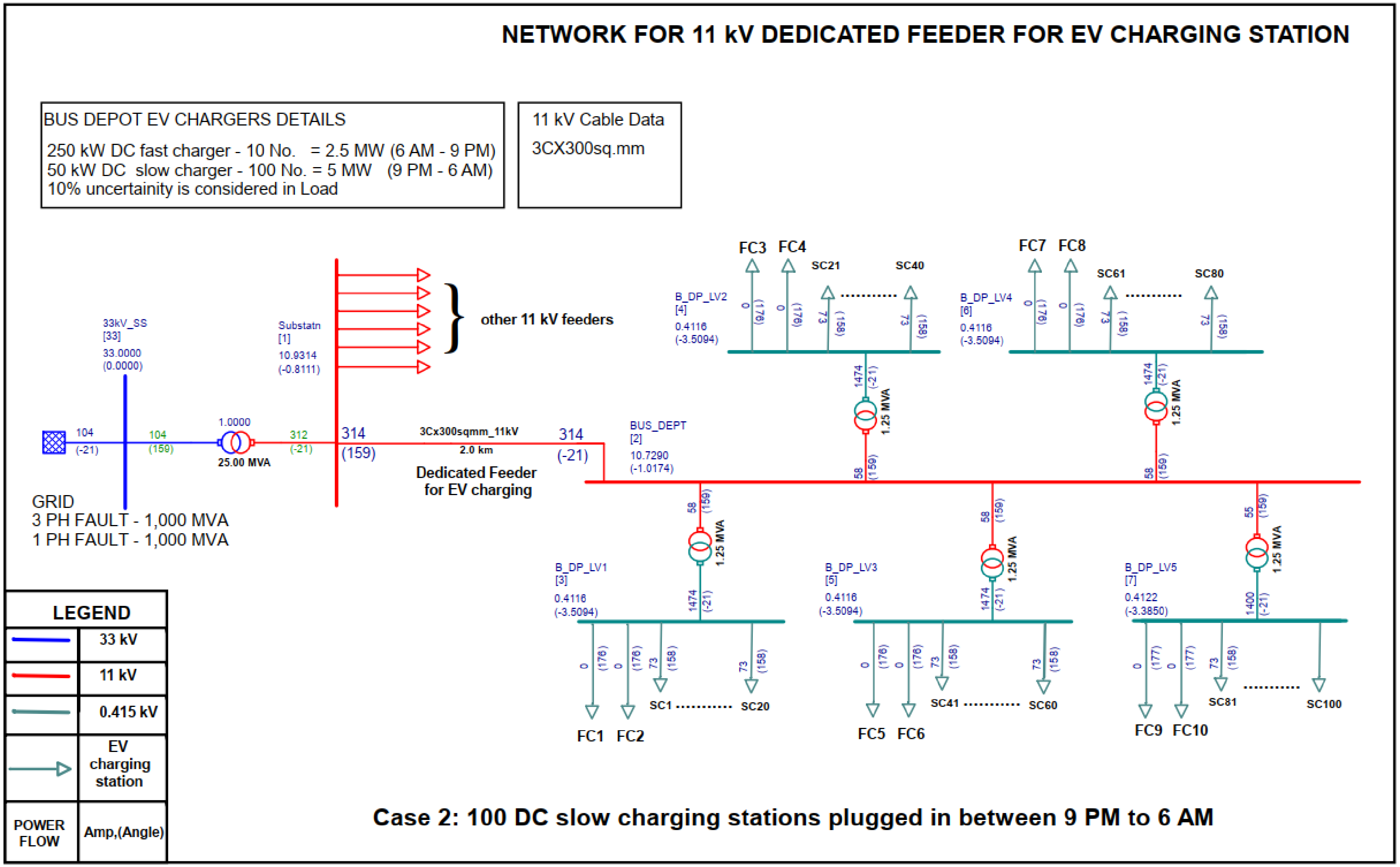


Figure 8.4.4: Current flow in dedicated feeder for EV charging stations at bus depot for Case-2

8.5 Power Quality Issues with EV Penetration

In a power system, any equipment which draws current from the supply in proportion to the applied voltage is termed as "linear" load. The term "nonlinear" is used to describe loads which draw current from the supply that is dissimilar in shape to the applied voltage. The majority of nonlinear loads are equipment's that utilize power semiconductor devices for power conversion.

The EV chargers are highly non-linear devices due to its operation principle and the presence of switching power semiconductor elements. Non-linear loads draw current in high amplitude in short pulses, which creates distortion in current and voltage wave shapes which are measured in term of Total Harmonics Distortion (THD).

Harmonics are currents or voltages with frequencies that are integer multiples of fundamental power frequency. Total Harmonics Distortion of current/voltage is the contribution of all the harmonic frequency currents/voltages to the fundamental.

The harmonic current content in charging current from EV chargers is generally quite high. The harmonics generated from the EV chargers may have adverse effect on electrical power equipments or its associated equipment. It may also degrade the power quality on the supply mains and it may affect users in the neighbourhood of the chargers. Hence harmonic current analysis considering the EV charging is an important study in the investigation of impact of EV charging on distributed systems.

8.5.1 Harmonic Distortion Limits

The IEEE Std. 519™-2014 'IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems' specifies the harmonic distortion limits and suitable recommendations.

The IEEE Std. 519™-2014 voltage distortion and current distortion limits for different voltage levels are presented in Table 8.5.1 and Table 8.5.2.

Table 8.5.1: IEEE Std. 519-2014: Voltage distortion limits

Bus Voltage at PCC	Individual Harmonic (%)	Total Harmonic Distortion THD (%)
1.0 kV and below	5.0	8.0
1.001 kV through 69 kV	3.0	5.0
69.001 kV through 161 kV	1.5	2.5
Above 161 kV	1.0	1.5

Table 8.5.2: IEEE Std. 519-2014: Current distortion limits for systems rated 120 V through 69 kV

Maximum harmonic current distortion in percent of IL						
Individual harmonic order (odd harmonics)						
ISC/IL	3≤h<11	11≤h<17	17≤h<23	23≤h<35	35≤h<50	TDD
<20*	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0

>1000	15.0	7.0	6.0	2.5	1.4	20.0
Even harmonics are limited to 25% of the odd harmonic limits above.						
*All power generation equipment is limited to these values of current distortion, regardless of actual ISC/IL						
ISC = maximum short-circuit current at PCC (Point of Common Connection) IL = maximum demand load current (fundamental frequency component) at PCC TDD = Total Demand Distortion						

From Table 8.5.2, it can be inferred that the current harmonic distortion is dependent on the short circuit level of the incoming supply and the maximum demand load current.

8.5.2 Janta Colony Feeder – Harmonic Analysis and Results

Janta colony 11 kV feeder emanates from 33/11 kV Dwarakapuri substation and consists of 10 distribution transformers in 7 different locations. Janta Colony feeder network has been presented in Figure 5.4.1

Under harmonic analysis, harmonics measured at EV charging stations (public/home/mall/office etc) and roof-top solar generation are injected in the simulation studies to find the harmonic levelsand compared with the standards of IEEE (distortion limits). This study will provide the information on how the EV charging stations will affect the grid voltage THD (Total Harmonic Distortion) level at 11kV side (HT) and 0.415kV side (LT) of distribution transformers.

Transformer details along with MVA capacity in Janta colony feeder are presented in Table 8.5.3.

Table 8.5.3: Janta Colony 11kV distribution transformer name and MVA capacity

Sl. No.	Transformer Name	Capacity
1	JANTA COLONY NO-7:PL-1	0.63 MVA
2	JANTA COLONY NO-7:PL-2	0.63 MVA
3	JANTA COLONY NO-6:PL	0.63 MVA
4	JANTA COLONY NO-5:PL-1	0.63 MVA
5	JANTA COLONY NO-5:PL-2	0.4 MVA
6	JANTA COLONY NO-4:PL-1	0.63 MVA
7	JANTA COLONY NO-4:PL-2	0.63 MVA
8	JANTA COLONY NO-3:PL	0.4 MVA
9	JANTA COLONY NO-2:PL	0.4 MVA
10	JANTA COLONY NO-1:PL	0.63 MVA
11	JANTA COLONY EV charging station	0.8 MVA

The following scenarios and corresponding cases have been considered for simulation of harmonics studies.

Scenario-1: Harmonics injection from EV charging points and solar rooftop generations (existing harmonics under DT are not considered for the analysis). The case studies considered for simulation are:

- Case-1: Injection of EV charging harmonics into the grid
- Case-2: Injection of EV charging harmonics into the grid along with solar PV inverter harmonics.

Scenario-2: Harmonics injection as per limits provided in IEEE standard.

The current sources are modelled as per the limits mentioned in IEEE standards which are cumulative of harmonics generated from harmonic sources. This case is performed to find the maximum impact on the grid if all connected EVs/solar PVs allowed up to its maximum harmonic limits as per IEEE Std.

The cases considered for simulation are the following:

- Case-1: Maximum Current Total Demand Distortion (ITDD) as per IEEE standards.
- Case-2: Maximum Individual harmonic currents distortion as per IEEE standards.
- Case-3: Maximum Voltage Total Harmonic Distortion (VTHD) as per IEEE Std by limiting Individual harmonic currents distortion.

8.5.2.1 Scenario 1 Harmonics Injection from EV Charging and Solar Rooftop Generation

Case-1: Injection of EV charging harmonics into the grid

Harmonics are injected at identified locations for public and home/work/mall charging stations.

Sample EV public charging station with individual harmonic current, % ITDD has been presented in Figure 8.5.1.

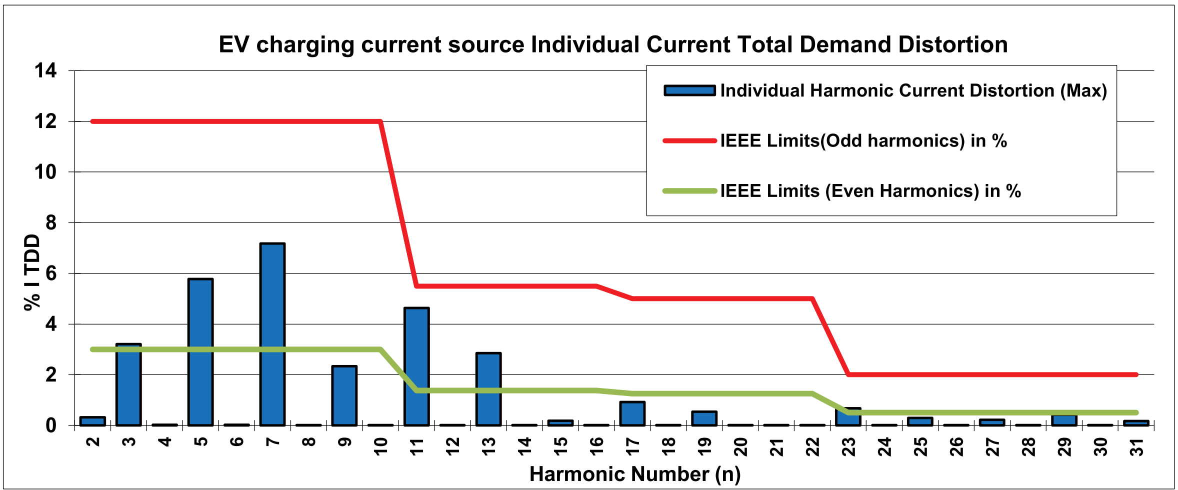


Figure 8.5.1: EV public charging station harmonics

With the above harmonic current injection, the simulated total voltage harmonic distortion levels for Janta colony feeder are compared with IEEE Std. and same is presented in Table 8.5.4.

Table 8.5.4: Janta Colony 11kV distribution transformer % VTHD for scenario-1, case-1

Sl. No.	Transformer Name	% VTHD on Trafo HT side 11kV by simulation	% VTHD limits as per IEEE 519	% VTHD on Trafo LT side 0.415kV by simulation	% VTHD limits as per IEEE 519
1	JANTA COLONY NO-7:PL-1	0.1238	5	0.3230	8
2	JANTA COLONY NO-7:PL-2			0.2580	8
3	JANTA COLONY NO-6:PL	0.1268	5	0.2657	8
4	JANTA COLONY NO-5:PL-1	0.1329	5	1.1833	8
5	JANTA COLONY NO-5:PL-2			0.1663	8
6	JANTA COLONY NO-4:PL-1	0.1348	5	0.1356	8
7	JANTA COLONY NO-4:PL-2			0.1320	8
8	JANTA COLONY NO-3:PL	0.1348	5	0.2016	8
9	JANTA COLONY NO-2:PL	0.1350	5	0.1749	8
10	JANTA COLONY NO-1:PL	0.1351	5	0.1598	8
11	JANTA COLONY EV charging station	0.1347	5	3.3608	8

Observations: From the simulation results, % VTHD at distribution transformers in 11kV Janta colony feeder are within acceptable limits as compared to IEEE standard.

Case-2: Injection of EV charging harmonics into the grid along with solar PV inverter harmonics.

Harmonics are injected at identified locations for public and home/work/mall charging stations and solar rooftop generations.

Sample solar PV rooftop inverter with individual harmonic current, % ITDD has been presented in Figure 8.5.12.

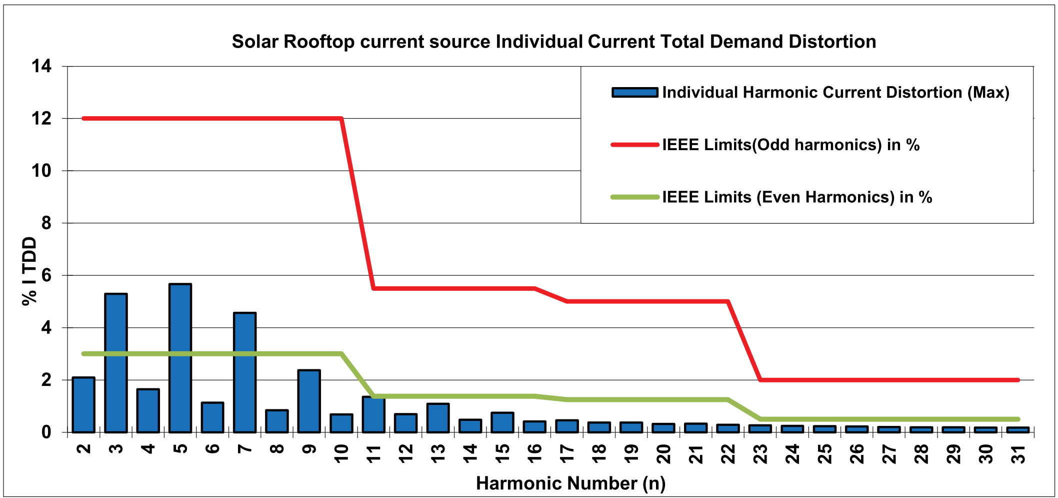


Figure 8.5.2: Solar rooftop injecting harmonics

With the above harmonic current injection, the simulated total voltage harmonic distortion levels for Janta colony feeder are compared with IEEE Std. and same is presented in Table 8.5.5.

Table 8.5.5: Janta Colony 11kV distribution transformer % VTHD for scenario-1, case-2

Sl. No.	Transformer Name	% VTHD on Trafo HT side 11kV by simulation	% VTHD limits as per IEEE 519	% VTHD on Trafo LT side 0.415kV by simulation	% VTHD limits as per IEEE 519
1	JANTA COLONY NO-7:PL-1	0.9854	5	2.8329	8
2	JANTA COLONY NO-7:PL-2			2.8022	8
3	JANTA COLONY NO-6:PL	0.9982	5	2.7425	8
4	JANTA COLONY NO-5:PL-1	1.0229	5	4.7352	8
5	JANTA COLONY NO-5:PL-2			2.2155	8
6	JANTA COLONY NO-4:PL-1	1.0353	5	3.4674	8
7	JANTA COLONY NO-4:PL-2			3.213	8
8	JANTA COLONY NO-3:PL	1.0334	5	2.8606	8
9	JANTA COLONY NO-2:PL	1.0402	5	2.5538	8
10	JANTA COLONY NO-1:PL	1.0416	5	2.6089	8
11	JANTA COLONY EV charging station	1.029	5	4.0552	8

Observations: From the simulation results, % VTHD at distribution transformers in 11kV Janta colony feeder are within acceptable limits as compared to IEEE Std limits.

8.5.2.2 Scenario 2: Harmonics Injection as per Limits Provided in IEEE standard.

Case-1: Maximum Current Total Demand Distortion (ITDD) as per IEEE standards.

Harmonics are injected at LT of distribution transformers. Sample injecting harmonics with individual % ITHD is present in Figure 8.5.3.

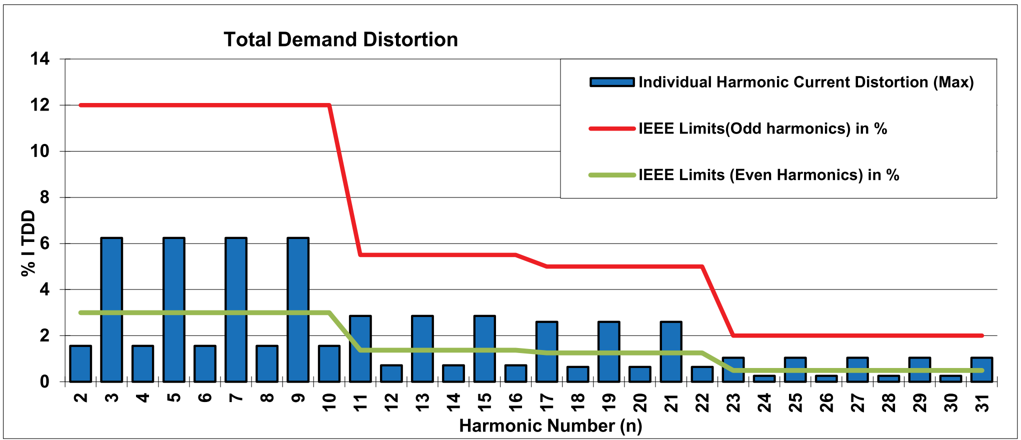


Figure 8.5.3: Total Demand Distortion (TDD) as per IEEE standards

With the above harmonic current injection, the simulated total voltage harmonic distortion levels for Janta colony feeder are compared with IEEE Std. and same is presented in Table 8.5.6.

Table 8.5.6: Janta Colony 11kV distribution transformer % VTHD for scenario-2, case-1

Sl. No.	Transformer Name	% VTHD on Trafo HT side 11kV by simulation	% VTHD limits as per IEEE 519	% VTHD on Trafo LT side 0.415kV by simulation	% VTHD limits as per IEEE 519
1	JANTA COLONY NO-7:PL-1	1.1643	5	3.6266	8
2	JANTA COLONY NO-7:PL-2			3.5461	8
3	JANTA COLONY NO-6:PL	1.1781	5	3.8563	8
4	JANTA COLONY NO-5:PL-1	1.2039	5	3.1853	8
5	JANTA COLONY NO-5:PL-2			4.8123	8
6	JANTA COLONY NO-4:PL-1	1.2156	5	2.8075	8
7	JANTA COLONY NO-4:PL-2			2.6114	8
8	JANTA COLONY NO-3:PL	1.2148	5	5.5296	8
9	JANTA COLONY NO-2:PL	1.2270	5	5.2494	8
10	JANTA COLONY NO-1:PL	1.2295	5	5.0953	8
11	JANTA COLONY EV charging station	1.2101	5	4.1428	8

Observations: From the simulation results, % VTHD at distribution transformers of 11kV feeder are within acceptable limits as compared to IEEE standard.

Case-2: Maximum Individual harmonic currents distortion as per IEEE standards.

Harmonics are injected at LT of distribution transformers. Sample current source injecting harmonics with individual % ITHD is present in Figure 8.5.4.

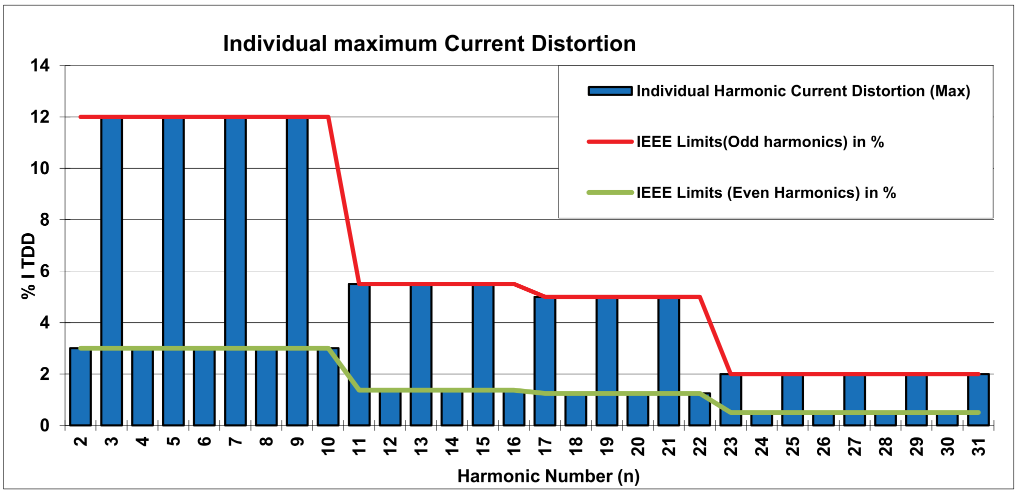


Figure 8.5.4: Individual maximum Current Distortion

With the above harmonic current injection, the simulated total voltage harmonic distortion levels of the feeder are compared with IEEE Std. and same is presented in Table 8.5.7.

Table 8.5.7: Janta Colony 11kV distribution transformer % VTHD for scenario-2, case-2

Sl. No.	Transformer Name	% VTHD on Trafo HT side 11kV by simulation	% VTHD limits as per IEEE 519	% VTHD on Trafo LT side 0.415kV by simulation	% VTHD limits as per IEEE 519
1	JANTA COLONY NO-7:PL-1	2.1154	5	6.8859	8
2	JANTA COLONY NO-7:PL-2			6.7291	8
3	JANTA COLONY NO-6:PL	2.1400	5	7.3263	8
4	JANTA COLONY NO-5:PL-1	2.1858	5	6.0310	8
5	JANTA COLONY NO-5:PL-2			9.1663	8
6	JANTA COLONY NO-4:PL-1	2.2069	5	5.3017	8
7	JANTA COLONY NO-4:PL-2			4.9222	8
8	JANTA COLONY NO-3:PL	2.2053	5	10.5488	8
9	JANTA COLONY NO-2:PL	2.2288	5	10.0087	8
10	JANTA COLONY NO-1:PL	2.2337	5	9.7116	8
11	JANTA COLONY EV charging station	2.1963	5	4.8558	8

Observations: From the simulation results, % VTHD at distribution transformers 1, 2, 3 and 5 are exceeding acceptable limits as compared to IEEE standard.

Case-3: Maximum Voltage Total Harmonic Distortion (VTHD) as per IEEE Std. by limiting Individual harmonic currents distortion.

Harmonics are injected at LT of distribution transformers where TDD is limited to 22% to maintain VTHD within IEEE Std limits. The limited Individual harmonics %ITDD is presented in Figure 8.5.5.

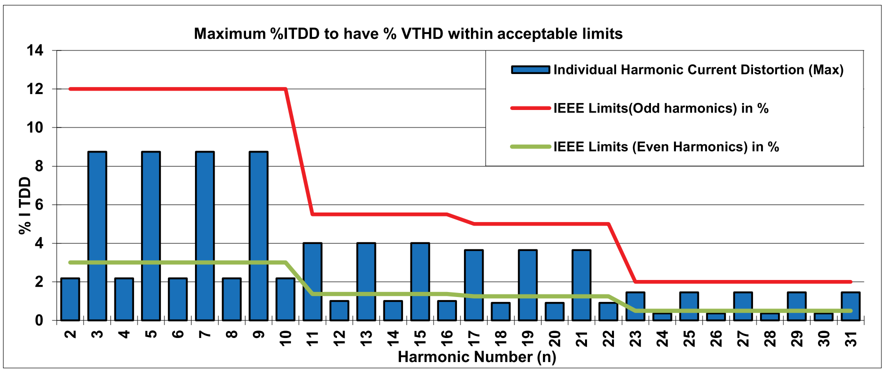


Figure 8.5.5: Current source injecting harmonics with maximum %ITDD to have % VTHD within acceptable limits

With the above harmonic current injection, the simulated total voltage harmonic distortion levels for Janta colony feeder are compared with IEEE Std. and same is presented in Table 8.5.8.

Table 8.5.8: Janta Colony 11kV distribution transformer % VTHD and % IEEE limits

Sl. No.	Transformer Name	% VTHD on Trafo HT side 11kV by simulation	% VTHD limits as per IEEE 519	% VTHD on Trafo LT side 0.415kV by simulation	% VTHD limits as per IEEE 519
1	JANTA COLONY NO-7:PL-1	1.6455	5	5.2763	8
2	JANTA COLONY NO-7:PL-2			5.1572	8
3	JANTA COLONY NO-6:PL	1.6648	5	5.6126	8
4	JANTA COLONY NO-5:PL-1	1.7007	5	4.6257	8
5	JANTA COLONY NO-5:PL-2			7.0161	8
6	JANTA COLONY NO-4:PL-1	1.7171	5	4.0698	8
7	JANTA COLONY NO-4:PL-2			3.7809	8
8	JANTA COLONY NO-3:PL	1.7159	5	8.0701	8
9	JANTA COLONY NO-2:PL	1.7338	5	7.6584	8
10	JANTA COLONY NO-1:PL	1.7375	5	7.4319	8
11	JANTA COLONY EV charging station	1.7090	5	4.4994	8

Observations: From the simulation results, % VTHD at distribution transformers are within acceptable limits as compared to IEEE standard.

8.5.2.3 Observations:

- No harmonic filter circuits are required when low penetration of EV and PV roof top generation present in the system.
- At high levels of EV and rooftop solar generation, voltage harmonics will exceed the IEEE 519 limits, when individual harmonic current injections are high and within the IEEE limits. Hence, harmonic filters are recommended under these conditions.
- Any violation of current harmonics injected by EVs or solar PV generation beyond the IEEE 519 limits to be taken care by consumer and violations in voltage harmonics taken care by BYPL with appropriate filters.

8.5.3 Methodology to Calculate Transformer Loss of Life due to Harmonics

In power distribution system, distribution transformer is most important apparatus. Many transformers are designed to operate at rated frequency with linear loads. However, the linear loads are gradually replacing with non-linear loads that inject harmonic currents [68] [69].

8.5.3.1 Transformer Losses

Transformers are designed to deliver the required power with maximum efficiency and minimum losses. Transformer losses are classified into no load losses and load losses.

$$P_T = P_{NL} + P_{LL}$$

PNL is no load losses or excitation loss due to induced voltage in core and due to magnetic hysteresis and eddy currents. PLL is the load loss and consists of I2R loss and stray loss caused by electromagnetic field in the windings, core, clamp, magnetic sheets, enclosures or tank walls etc. I2R is calculated by measuring the dc resistance of winding and multiplying it with square of the load current. The stray losses can be further divided into winding stray loss and stray loss in components other than winding (POSL). The winding stray loss includes winding conductor strand loss and loss due to circulating currents between strands or parallel winding circuits.

The total load loss can be expressed as:

$$P_{LL} = P_{I^2R} + P_{EC} + P_{OSL}$$

where,

P_{LL} = Load loss

P_{EC} = Winding eddy-current loss

P_{OSL} = other stray loss

The total stray losses are determined by subtracting I^2R from the load losses measured during the impedance test.

$$P_{TSL} = P_{LL} - P_{I^2R}$$

where,

P_{TSL}= Total stray loss

A. Eddy current losses in winding

This loss is due to time variable electromagnetic field across windings. There are two effects that can cause increase in eddy current loss in windings, skin effect and proximity effect. In transformers, internal windings adjacent to core have more eddy current loss, in comparison to external windings. This is due to high electromagnetic intensity near the core that covers these windings. The winding eddy current loss in the power frequency spectrum tends to be proportional to the square of the load current and the square of frequency, which are due to both the skin effect and proximity effect.

$$P_{EC} \alpha I^2 * f^2$$

The impact of lower order harmonics on the skin effect is negligible in the transformer winding.

A portion of stray loss is taken to be eddy current loss. For oil type transformer the winding eddy loss is assumed to be:

$$P_{EC} = 0.33 P_{TSL}$$

For dry type transformer the winding eddy loss is assumed to be

$$P_{EC} = 0.67 P_{TSL}$$

$$P_{OSL} = P_{TSL} - P_{EC}$$

The division of eddy current loss and other stray loss is assumed to as follows

- **60% in low voltage winding and 40% in the high voltage winding for all transformers having a maximum current rating of less than 1000A (regardless of turn ratio).**
- **60% in low voltage winding and 40% in the high voltage winding for all transformers having a turn ratio of 4:1 or less.**
- **70% in low voltage winding and 30% in the high voltage winding for all transformers having a turn ratio greater than 4:1 and also having one or more winding with a maximum cooled current rating greater than 1000 A.**

Eddy current loss may also be calculate from the equation

$$P_{TSL} = P_{LL\_R} - (R_1 I_{1-R}^2 + R_2 I_{2-R}^2)$$

B. Other stray losses in Transformer

Each metallic conductor by electromagnetic flux experiences an internally induced voltage that causes eddy currents to flow in that ferromagnetic material. The eddy current produce losses that are dissipated in the form of heat, producing an additional temperature rise in the metallic parts over its surroundings. The eddy current losses outside the windings are other stray losses. The other stray losses in core, clamp and structural parts will increase at a rate proportional to the square of the load current but not a rate proportional to the square of the frequency as in eddy current winding losses.

$$R_{OSL} = 1.29\left(\frac{f_h}{f_1}\right)^{0.8} \quad m\Omega$$

Thus this loss is proportional to square of the load current and the frequency of to the power of 0.8.

Given equation can be used to calculate the other stray losses.

$$P_{OSL} = P_{TSL} - P_{EC}$$

8.5.3.2 Effect of Harmonics on Transformer

A. Effect of Voltage Harmonics

According to Faraday's law the terminal voltage determines the transformer flux level

$$N\frac{d\Phi}{dt} = v(t)$$

Transferring this equation in frequency domain shows the relation between the voltage harmonics and the flux components.

$$Nj(h\omega)\varphi_h = V_h$$

This equation shows that the flux magnitude is proportional to the voltage harmonics and inversely proportional to harmonic order h. Furthermore within most power systems the harmonic distortion of the system voltage THD is well below 5% and the magnitude of voltage harmonics components are small compared to the fundamental component, rarely exceeding a level of 2-3%. Therefore neglecting the effect of harmonic voltage and considering the no load losses caused by the fundamental voltage component will only give rise to insignificant error. If THDV is not negligible, losses under distorted voltage can be calculated based on ANSI-C.27-1920 standard.

$$P = P_M \left[P_h + P_{ec} \left(\frac{V_{hrms}}{V_{rms}} \right)^2 \right]$$

where V_{hrms} and V_{rms} are the rms values of distorted and sinusoidal voltages, PM and P are no load losses under distorted and sinusoidal voltages, Ph and Pec are hysteresis and eddy current losses, respectively.

B. Effect of Current Harmonics

In most of the power systems, current harmonics are of significance. These harmonics current components cause additional losses in the windings and other structural parts.

i.Effect of Harmonics on dc losses

If the rms value of the load current is increased due to harmonic components, then these losses will increase with the square of the current.

$$P_\Omega = R_{dc} * I_{2A} = R_{dc} * \left(\sum_{h=1}^{h=\max} I_{hrms}^2 \right)$$

ii. Effect of harmonics on eddy current losses

The eddy current losses generated by the electromagnetic flux are assumed to vary with the square of the rms current and the square of frequency:

$$P_{ec} = P_{ec-R} \sum_{h=1}^{h=\max} h^2 \left(\frac{I_h}{I_R} \right)^2$$

where,

I_h = RMS current at harmonic h

I_R = RMS fundamental current under rated frequency and rated load conditions

iii. Effect of harmonics on other stray losses

The other stray losses assumed to vary with the square of the rms load current and the harmonic frequency to the power of 0.8.

$$P_{OSL} = P_{OSL-R} \sum_{h=1}^{h=\max} h^{0.8} \left(\frac{I_h}{I_R} \right)^2$$

8.5.3.3 Procedure for Evaluation of Losses and Capacity of Transformer Supplying Non Linear Load

The equation that applies to linear load condition is

$$P_{LL-R}(pu) = 1 + P_{EC-R}(pu) + P_{OSL}(pu)$$

where, P_{LL-R} rated load losses, 1 is dc losses, P_{EC-R}, is rated winding eddy current loss,

POSL is rated other stray losses at rated current.

As the effect of the harmonic on losses of transformer evaluated in previous sections, a general equation for calculation of losses when transformer supplying a harmonic load can be defined as:

$$P_{LL}(pu) = I^2(pu) * [1 + F_{HL} * P_{ec-R}(pu) + F_{HL-STR} * P_{OSL-R}(pu)]$$

The permissible transformer current is expressed as:

$$I_{\max}(pu) = \sqrt{\frac{P_{LL-R}(pu)}{[1 + [F_{HL} * P_{ec-R}(pu)] + [F_{HL-STR} * P_{OSL-R}(pu)]]}}$$

From the above mentioned equation, the permissible current and de-rating of the transformer can be determined

8.5.3.4 Transformer Loss of Life Calculation

Harmonic losses occur in the form of increased heat dissipation in the winding and skin effect. Both are a function of the square of the root mean square current. This extra heat has a significant impact in reducing the operating life on the insulation of a transformer. The estimation transformer loss of life is based the deterioration rate achieved by insulating materials. The transformer loss of life is based on the deterioration rate achieved by insulating materials. About 50% of a transformer loss of life is caused by thermal stress which is produced by the nonlinear load.

The top oil temperature rise is calculated as follows [69]:

$$\Delta\theta_{TO} = \theta_{TO-Rated}\left(\frac{P_{LL} + P_{NL}}{P_{LL-RATED} + P_{NL}}\right)^{0.9}$$

Where,

$\theta_{TO-Rated}$ = top oil temperature rise over ambient under rated conditions

$P_{LL-RATED}$ = load losses under rated conditions

P_{NL} = no load losses

P_{LL} = load losses, increased to account for harmonic load currents

The hottest spot winding temperature rise over top oil is calculated as follows

$Ø_g = Ø_{g-R}(P_{LL}/P_{LL-R})^{0.8}$

Where,

$Ø_{g-R}$ = Rated hot spot winding temperature rise over top oil

The hot spot temperature is

$Ø_H = Ø_A + \Delta Ø_{TO} + Ø_g$

where,

A = Ambient temperature

$_H$ = Hot Spot temperature

The relative aging factor and real life of a transformer can be expressed as

$$F_{AA} = \exp\left(\frac{15000}{383} - \frac{15000}{\theta_H + 273}\right)$$

where,

FAA =relative ageing factor

$$Life(pu) = 9.8 * 10^{-18} e^{\left(\frac{15000}{\theta_H + 273}\right)}$$

Real life = Life (pu) *normal insulation life or

Real life = normal insulation life (years)/FAA

8.5.3.5 Impact of Current Harmonics on Transformer Life

Input data considered for calculation has been presented in Table 8.5.9.

Table 8.5.9: Input data considered for calculation

Sl No	Description	Value
1	Transformer kVA	200
2	Temperature base for losses	75
3	No load Losses W	500
4	winding losses W	1963
5	Winding eddy current losses PEC	177
6	Other stray losses POSL	294
7	Top oil rise over ambient (Rated)	65
8	Hot spot temperature rise over top oil (Rated)	10
9	Normal insulation life (years)	20.55

Sample harmonic current Spectrum with different individual harmonics used in simulation studies are presented in Table 8.5.10. The same is used to find the impact of current harmonics on transformer life. Case-1 is selected with high ITDD of above 20% to find the worst case scenario on transformer life. Case-2 is selected with ITDD of 15% is selected to limit the current harmonics as per the IEEE 519. Case-3 with ITDD of 10.8% is selected as per the current harmonics presented in Figure 8.5.1. Case-4 with ITDD of 7.5% is selected as per the current harmonics presented in Figure 8.5.2. Case-5 is created by sensitivity study to find the amount of ITDD where the transformer life will start reducing more.

Table 8.5.10: Sample harmonic current Spectrum

Case	%ITDD	Harmonic spectrum (harmonic order)								
		1	5	7	11	13	17	19	23	25
Case-1	22	1	0.1760	0.1100	0.0447	0.0264	0.0118	0.0106	0.0087	0.0086
Case-2	15	1	0.0938	0.0963	0.0632	0.0304	0.0102	0.0037	0.0043	0.0092
Case-3	10.8	1	0.0577	0.0718	0.0463	0.0286	0.0092	0.0055	0.0068	0.0030
Case-4	7.5	1	0.0567	0.0457	0.0136	0.0108	0.0046	0.0037	0.0027	0.0023
Case-5	8	1	0.0494	0.0507	0.0333	0.0160	0.0053	0.0019	0.0022	0.0049

Sample calculation for case-1 with ITDD of 22 % is presented below. Substituting values in below equations we obtain,

$$P_{\Omega} = R_{dc} * I_{2A} = R_{dc} * \left(\sum_{h=1}^{h=\max} I_{hrms}^2 \right)$$

= 2142.44 W

$$P_{ec} = P_{ec-R} \sum_{h=1}^{h=\max} h^2 \left(\frac{I_h}{I_R} \right)^2$$

= 475.65 W

$$P_{OSL} = P_{OSL-R} \sum_{h=1}^{h=\max} h^{0.8} \left(\frac{I_h}{I_R} \right)^2$$

= 334.08 W

Total loss under harmonic loads= 3452.7 W

Total loss under linear loads = 2934.05 W

$$\Delta\theta_{TO} = \theta_{TO-Rated} \left(\frac{P_{LL} + P_{NL}}{P_{LL-RATED} + P_{NL}} \right)^{0.9}$$

= 65*(3452.8/2934.05) ^0.9 = 75.25

$Ø_g = Ø_{g-R} (P_{LL}/P_{LL-R})^{0.8}$ = 10*(2952.8/2434.05)^0.8 = 11.67

$Ø_H = Ø_A + \Delta Ø_{TO} + Ø_g$ = 35+75.25+11.67 = 121.9

$$Life(pu) = 9.8*10^{-18} e^{\left(\frac{15000}{\theta_H + 273} \right)}$$

= 0.3 pu

Real life = Life (pu) *normal insulation life = 0.3*20.55 = 6.3 years

Hence transformer will have life of 6.3 years instead of 20.55 years when current harmonics is 22 %

The transformer life calculated for various cases are presented in Table 5.5.11.

Table 8.5.11: Impact of current harmonics on Transformer life

Case	%ITDD	Available Transformer life (designed for 20.55 years)
Case-1	22	6.3
Case-2	15	9.2
Case-3	10.8	14.5
Case-4	7.5	19.6
Case-5	8	17.4

From Table 8.5.11, it is observed that the effect of current harmonics on life of transformer is very high. When current harmonics, ITDD is more than 7.5%, transformer life will start deteriorate exponentially. Hence harmonic filters are recommended to be connected at transformer feeder when current harmonics are more than 7.5% for longer durations even though IEEE 519 Std allows the ITDD up to 15% as shown in Table 8.5.2.

09

Extrapolation of the Results to the Entire BYPL DISCOM for the Year 2030

9.1 Impact of EV Penetration on Janta Colony Feeder for the Year 2030

From the simulation studies, the following conclusions are drawn and are used to extrapolate the outcomes at DISCOM level for the year 2030.

1. From Case-1, Janta Colony feeder, the peak power and energy requirement per day for EV charging is observed as 173.9 kW and 2.35 MWh respectively. The individual peak power and average energy for each DT with EV charging is presented in Table 9.1.1.

Table 9.1.1: Peak power and energy consumption by EV for each DT in Janta colony

Sl. No.	DT Name	Peak power with EV charging in kW	Energy consumption per day in kWh
1	JCN1_PM_630KVA	21.79	100
2	JCN2_400KVA	23.45	194
3	JCN3_PM_630KVA	24.16	275
4	JCN4_PL1_630KVA	28.80	160
5	JCN4_PL2_630KVA	3.55	45
6	JCN5_PL1_630KVA	32.83	351
7	JCN5_PL2_400KVA	24.04	234
8	JCN6_PL_630KVA	39.92	524
9	JCN7_PL1_630KVA	31.88	246
10	JCN7_PL2_630KVA	38.86	219
Total		**269.28**	**2348**

2. From Table 6.1.1, the diversity factor of the EV charging distribution in Janta colony feeder is calculated as,

Diversity Factor = Individual peak demand of DTs/total feeder peak demand

= 269.28/173.9 = 1.55 …… (1)

From (1), it is evident that all EVs under each DT are not connected to the grid at all times and shown by the diversity factor of value 1.55.

It should be noted that EV penetration of 3 charging locations (Home, Office/Work and Mall/parking) are considered in the simulation studies against 6 charging location as presented in Table 3.27. However, all 6 categories are considered while finding the impact of EV penetration at DISCOM level in sections further.

Load Factor (for 24 hours) = average demand/maximum demand

= 2348/ (173.9*24) = 0.56 …..(2)

It should be noted that current year load factor of Janta colony is 0.526 (taking total energy consumption and maximum demand over a period of 1 year).

Hence, by comparing the load factor of EV charging (0.56) and current year consumer load factor (0.526), the charging behaviour of EVs (derived from the methodology which is used in the simulation studies) is similar to the behaviour of conventional consumers.

3. The EV charging energy as per battery capacity and initial SoC of 25% is presented in Table 6.1.2.

Table 9.1.2: Battery charging energy consumption with SoC of 25%

EV Category	Battery Capacity in kWh	EV charging Energy per charge in kWh
2W	4	3
3W - PV	7	5.25
3W - CV	9	6.75
4W - PV	80	60
4W - CV	80	60
Bus	250	187.5

9.2 Impact of EV Penetration at Feeder Level for 2030

From Table 6.1.1, it is noted that at any given point of time, the following 3 charging location (Home, Office/Work and Mall/parking) are connected with EVs under Janta colony feeder. The rest of the other EVs are connected to other feeders at different places such as, dedicated, swapping or public charging Station. For example, in the simulation studies performed for 24 hours (12 AM-12 AM), DT 10, case-1 for Janta colony, a combination of partial and full charge requirements are considered; 15 numbers of 2W with SOC of 25%, 4 numbers of 3W and 3 numbers of 4W with SoC of above 25%. The study resulted at an energy consumption of 219 kWh as shown in Table 6.1.1. The variation in SoC of above 25% is due to the partial charging completed during the previous day. This is in line with the battery capacities and SoC as presented in Table 6.1.2. Hence, the simulation studies are in-line with calculations made with EV battery capacity and initial SoC. Hence, all charging locations presented in

Table 8.2.8 are considered to assess the energy requirements for selected feeders as per the number of vehicles projected with initial SoC of 25% and same is presented from Table 9.2.1 to Table 9.2.3.

Table 9.2.1: Annual Energy requirement with high capacity EVs for Janta Colony feeder area

EV type	Battery Capacity in kWh	EV charging Energy per charge in kWh with SoC of 25%	No of EVs	No of Charges per EV per year	Annual EV charging Energy in MWh
2W	4	3	701	65	137
3W - PV	7	5.25	128	594	399
3W - CV	9	6.75	9	441	27
4W - PV	80	60	251	48	723
4W - CV	80	60	25	292	438
Bus	250	187.5	5	389	365
Total					**2088**

Table 9.2.2: Annual Energy requirement with high capacity EVs for Arya Samaj feeder

EV type	Battery Capacity in kWh	EV charging Energy per charge in kWh	No of EVs	No of Charges per EV per year	Annual EV charging Energy in MWh
2W	4	3	927	65	181
3W - PV	7	5.25	169	594	527
3W - CV	9	6.75	12	441	36
4W - PV	80	60	332	48	956
4W - CV	80	60	34	292	596
Bus	250	187.5	6	389	438
Total					**2733**

Table 9.2.3: Annual Energy requirement with high capacity EVs for MVR Sadar feeder

EV type	Battery Capacity in kWh	EV charging Energy per charge in kWh	No of EVs	No of Charges per EV per year	Annual EV charging Energy in MWh
2W	4	3	377	65	74
3W - PV	7	5.25	69	594	215
3W - CV	9	6.75	5	441	15
4W - PV	80	60	135	48	389
4W - CV	80	60	14	292	245
Bus	250	187.5	3	389	219
Total					**1156**

From Table 9.2.1 to Table 9.2.3, it is observed that the required energy for EV charging for the year 2030 is around 2.08 MU, 2.73 MU and 1.15 MU respectively for Janta colony, Arya Samaj and MVR Sadar feeders. As seen in simulation studies of Janta colony for case 1, the load factor of EV charging is 0.56. The same load factor is used to find the feeder peak load and is presented in Table 9.2.4.

Table 9.2.4: Feeder Energy and Peak Load requirement for EV charging for the year 2030

Feeder	Feeder Energy/ Year in MU in the year 2018	Peak Load recorded in the year 2018	Energy for EV charging/Year in MU for the year 2030	Peak Load for EV charging in kW for the year 2030
Janta Colony	13.6	3.8	2.08	424
Arya Samaj	13.1	4.32	2.73	556
MVR Sadar	9.94	5.64	1.15	235

9.3 Impact of EV penetration at BYPL Level for 2030

Taking the feeder level outcomes further to BYPL area level, the required energy for BYPL is presented in Table 9.3.1. Considering the BYPL current year load factor of 0.48, the estimated peak demand due to EVs in the system for the year 2030 is around 361 MW.

Table 9.3.1: Energy and Peak demand requirement for EV charging for BYPL for the year 2030

EV type	Battery Capacity	EV charging Energy per charge in kWh	No of EVs	No of Charges per EV per year	EV charging Energy in MU
2W	4	3	509281	65	99
3W - PV	7	5.25	93083	594	290
3W - CV	9	6.75	6571	441	20
4W - PV	80	60	182467	48	526
4W - CV	80	60	18478	292	324
Bus	250	187.5	3547	389	259
Total					**1517**

Projected energy requirement for BYPL for the year 2019-20 is 6925 MU (without losses) and with growth rate of 4.76% (considering last 8 years historical energy sales), it will reach around 11022 MU by 2030. Hence, the increase in energy sales by normal growth rate is around 4097 MU. From Table 9.3.1, the energy consumption of EVs amount to 1517 MU which adds up to the total energy requirement of BYPL, 12539 MU. The summary of the EV contribution for BYPL is presented in Table 9.3.2. Considering the last two years peak demand and estimated peak demand by BYPL of the next year (1459MW, 1561MW, 1640MW) growth rate of 6% is considered for peak demand projection.

Table 9.3.2: Summary of EV penetration impact on BYPL network

Projected Energy requirement for year 2019-20 without losses, projected by BYPL [72]	6925 MU
Energy projection by 2030 without EV and without losses considering growth rate of 4.76%	11022 MU
Projected Peak demand for the year 2019-20 by BYPL	1640 MW
Projected Peak demand for the year 2029-30 by CAGR of 6% as per historical growth without EVs	2943 MW
Additional energy requirement with EV penetration for the year 2030	1517 MU
% Energy consumption by EV for the year 2030 with reference to energy sales without EVs	13.8%

Energy requirement of BYPL with EV penetration for the year 2030	12539 MU
Peak demand contribution of EVs as per the BYPL current load factor of 0.48	361 MW
% peak demand consumption by EV for the year 2030 with reference to peak demand without EVs in the system	12.3%

The demand raised due to EVs can be partially met by considering energy generated using solar PV generation for the year 2030 at 20% penetration level, i.e around 2000 MU. To achieve better utilization of solar roof-top penetration, either Time of Usage (ToU) or Time of Day (ToD) tariff can be implemented when high EV penetration occurs.

9.4 Impact of EV penetration at BYPL Level for 2023

The required energy for BYPL is presented in Table 6.4.1. Considering the BYPL load factor of 0.48, the estimated peak demand due to EVs in the system for the year 2023 is around 66 MW.

Table 9.4.1: Energy and Peak demand requirement for EV charging for BYPL for the year 2023

EV type	Battery Capacity	EV charging Energy per charge in kWh	No of EVs	No of Chargers per EV per year	EV charging Energy in MU
2W	1.5	1.125	90899	130	13
3W - PV	4	3	59093	608	108
3W - CV	7	5.25	746	389	2
4W - PV	15	11.25	39044	145	64
4W - CV	15	11.25	2492	886	25
Bus	120	90	439	811	32
Total					**243**

Projected energy requirement for BYPL for the year 2019-20 is 6925 MU (without losses) and with growth rate of 4.76%, it will reach around 7961 MU by 2023. Hence increase in energy sales by normal growth rate is around 922 MU. Hence the added energy requirement with EVs with 243 MU contributes the total energy requirement of BYPL to 8090 MU. The summary of the EV contribution for BYPL is presented in Table 9.4.2.

Table 9.4.2: Summary of EV penetration impact on BYPL network for the year 2023

Projected Energy requirement for year 2019-20 without losses by BYPL [72]	6925 MU
Energy projection by 2023 with EV and without losses with growth rate of 4.76%	7961 MU
Energy requirement with EV penetration for the year 2023	243 MU
% Energy consumption by EV by the year 2023 with reference to conventional energy projection	3.1%
Energy requirement of BYPL with EV penetration for the year 2023	8204 MU

9.5 Additional Revenue Requirement Due to EV Penetration for 2030 and 2023

Energy sales projected by BYPL for FY 2019-20 is 6925 MU [72] and same is furnished in Table 9.5.1,

Table 9.5.1: Energy Requirement for FY 2019-20 [72]

Sl. No	Particulars	Unit	Quantity
A	Energy sales	MU	6925
B	Energy requirement	MU	7737
C	Distribution loss	MU	812
D	Peak Demand projected	MW	1640

Aggregate revenue requirement estimated by BYPL for FY 2019-20 is 5030 crores [72] and same is furnished in Table 9.5.2.

Table 9.5.2: Aggregate Revenue Requirement for FY 2019-20 (Rs. Crore) [72]

Sl. No	Particulars	Amount (Crore)
A	Power Purchase Cost including Transmission Charges	3597
B	O&M Expenses	707
C	Additional O&M Expenses	146
D	Depreciation	196
E	Return on Capital Employed (RoCE)	470
F	Less: Non-Tariff income	-86
G	Aggregate Revenue Requirement excl. Carrying Cost on RA	5030

As per Table 9.5.1 and Table 9.5.2, the peak demand in MW and aggregate revenue requirement (ARR) are used to calculate ARR per MW and is furnished in Table 9.5.3.

Table 9.5.3: Aggregate Revenue Requirement per MW for the year 2019-20

Particulars	Unit	Amount in Crores
ARR	Crores	5030
Peak Demand	MW	1640
ARR per MW load	Crores per MW	3.07

With ARR per MW calculated as presented in Table 9.5.3, the additional ARR owing to inclusion of EV penetration in the system is projected for FY 2029-2030 and works out to 1108 crores. The total ARR calculated for FY 2029-30 without EVs amounts to 9035 crores and same is presented in Table 9.5.4.

Table 9.5.4: Aggregate Revenue Requirement for 2030

FY 2029-30		
Particulars	Unit	Value
Projected Peak demand for the year 2029-30 by CAGR of 6.02% as per historical growth without EVs	MW	2943
Additional peak load due to EVs in FY 2029-2030	MW	361
Additional ARR owing to inclusion of EV penetration in the system, projected for FY 2029-2030	Crores	1108
The total ARR calculated for FY 2029-30 without EVs	Crores	9035
% Increase in ARR owing to EV penetration	%	12.3%

10

Conclusions

The addition of EVs on the grid will have impacts on two aspects: one on technical and other on commercials. From the extrapolation of simulation results at DISCOM level with projected EVs on the system, the following conclusions and recommendations are made for BYPL.

- As shown via different simulations, peak load coming from EV charging may not pose a significant toll on the existing business-as-usual infrastructure upgradation plan. The load factor from EV charging closely matches with DISCOM's other loads and hence can be planned on as is basis rather than a drastic change or investments. With clear and evolving policies on EV adoption trends, DISCOM can undertake the required local distribution transformer level interventions and splitting of feeders to take more loads. Irrespective of EVs growth rate, DISCOM shall be able to manage the load with right balance of network addition, TOU and strong backend for controlled/managed EV charging options.
- Decentralized solar growth shall be good for the grid and with combination of TOU, the EV charging load can be shifted to solar hours to manage the peak better and also avoid reverse power in the network. 40% of capacity allocation for solar should work well at distribution level.
- Bulk Grid Energy Storage for absorbing any impact from EVs or solar is not required and will not be viable in current economics. It should have a stand-alone business case for specific commercial application and when integrated into the grid with high EVs, wherein the solar penetration does not seem to pose a challenge. In fact, it can help to optimize the grid better. But for the next few years, it is not an economical option to scale. Technology pilots should however be encouraged.
- DISCOM should build and integrate strong back-end for its Grid to receive and send communication and control signals to EVSE and their multiple charging or energy operators to achieve the necessary grid balance. A standard is being worked upon for this in India and DISCOM can rightly integrate it with its smart grid measures, including Demand Response (DR), peak cutting (cut supply to avoid charging during peak load or other defined event) and TOU integration.
- Devising separate EV tariff is a new trend to have price distinction on basis of type of loads within a single premise. This shall require the use of separate meters for EVs. DISCOM should re-evaluate its meter change plans and provide end-customers an opportunity to use an integrated meter with TOU and other EV supporting smart features.
- DISCOM should strongly follow EVSE and Grid connectivity standards and practices for safe installation and management.
- As per the EV projections and EV charging patterns presented in the methodology, un-controlled EV charging will contribute around 13.8% of energy sales for the year 2030.
- Similarly, un-controlled EV charging will contribute around 12.3% of peak demand for the year 2030. The additional peak demand of the system can be met by building the grid infrastructure to

accommodate the EV penetration. The investments for the new grid infrastructure will increase by 12.3% of total BYPL's worth. Hence, it is recommended to adopt controlled charging and/or Time of day or Time of Usage tariff to minimize the impact on peak load. This will minimize the grid infrastructure cost considerably.

- From the simulation studies, it is observed that addition of solar roof top PV generation in the system and moving the EV charging preferences to day time will minimize the grid impacts and grid infrastructure. With 20% solar PV penetration, i.e. 2100 MU for the year 2030, majority of EV energy sales can be absorbed during day time by enabling simple Time of Day (ToD) tariff.

  Power Quality issues like harmonics in the system is one of the continuous monitoring activities for Distribution companies, especially when large EV and solar roof top PV generation exist in the grid. From the harmonic studies performed, the following steps can be taken care by BYPL,

- All EV charging stations located at public places, malls, commercial buildings and dedicated chargers shall limit the injection of individual harmonic currents as per limits of IEEE 519 Std. If any EV charging station violates the current harmonic limits, the same shall be penalized commercially or injected harmonics shall be compensated with filter circuits by EV charging station.
- In case, injection of individual harmonic currents are within the IEEE 519 Std and voltage harmonic limits are beyond the limits, BYPL needs to take up necessary steps to limit the voltage harmonics within the limits by placing filters at appropriate places. This scenario may occur when the feeder has existing harmonics in the system due to the presence of larger industrial/commercial consumers or large solar PV penetration along with additional EV charging stations further on the feeder.
- From the calculations presented, it is observed that the effect of current harmonics on life time of the transformer is very high. When current harmonics, ITDD (Current Total Demand Distortion) is more than 7.5%, the transformer's life time deteriorates exponentially. Though IEEE Std 519 allows Current ITDD of 15%, harmonic filters are recommended to be connected at transformer when harmonic ITDD is more than 7.5% to save the life time of the transformers.

11

References

[1] CIGRE Working group C6.20 Report on "Integration of Electric Vehicles in Electric Power Systems" Sep 2015.

[2] Society of Indian Automobile manufacturers (SIAM) http://www.siamindia.com/statistics.aspx?mpgid=8&pgidtrail=14

[3] "Electric Vehicle Charging Station Guidebook-Planning for Installation and Operation", Chittenden County RPC, June 2014.

[4] EPRI Report on "Transportation Electrification: A Technology Overview," 2011.

[5] Khurram Afridi, "Wireless Charging of Electric Vehicles," Frontiers of Engineering: Reports on Leading-Edge Engineering from the 2017 Symposium.

[6] ISGF White Paper on "Electric Vehicle Charging Stations Business Models for India" by India Smart Grid Forum.

[7] Michael Nicholas and Dale Hall, "Lessons learned on early Electric vehicle fast-charging Deployments," published by ICCT, July 2018.

[8] Wajahat Khan, Furkan Ahmad, Aqueel Ahmad, Mohd. Saad Alam, Akshay Ahuja, "Feasibility Analysis of Electric Vehicle Charging Infrastructure Development on India", India Smart Grid Forum-2017.

[9] Xun Gong, Jayanth Rangaraju, "Taking charge of electric vehicles – both in the vehicle and on the grid," TEXUS Instruments, March 2018.

[10] Fitzgerald, G. & Nelder, C. (2017). EVgo fleet & tariff analysis phase 1: California. Retrieved from Rocky Mountain Institute website: https://www.rmi.org/wp-content/uploads/2017/04/eLab_EVgo_Fleet_and_Tariff_Analysis_2017.pdf

[11] Eric Khoo, James Gallagher, "Emerging Electric Vehicle Market & Business Models and Interoperability Standards," CIGRE 2012.

[12] Shawn Chandler, John Gartner, and Derek Jones, "Integrating electric vehicles with energy storage and Grids," IEEE Electrification Magazine, Sep 2018.

[13] Eurelectric, 2010. Market Models for the Roll-out of Electric Vehicle Public Charging Infrastructure. A Eurelectric Concept Paper. September 2010

[14] Grid-4-Vehicles EU FP7 project, "Deliverable 3.1-Report on the economic and environmental impacts of large-scale introduction of EV/PHEV including the analysis of alternative market and regulatory structures", Editors A. Shakoor and M. Aunedi, available at: http://www.g4v.eu/datas/reports/G4V_WP3_D3_1_economic_and_environmental_impact.pdf

[15] RTE, Generation adequacy report on the electricity supply-demand balancing, 2009 edition, available at: http://clients.rte-france.com/htm/an/mediatheque/telecharge/generation_adequacy_report_2009.pdf

[16] C. L. Moreira, D. Rua, "Extend Concepts of MG by Identifying Several EV Smart Control Approaches to be embedded in the Smartgrid Concept to manage EV individually or in Clusters", Mobile Energy Resources in Grids of Electricity, Deliverable D1.2, June 2010. Available: http://www.ev-merge.eu/

[17] Q.Gong, et al.,"Study of PEV Charging on Residential Distribution Transformer Life," (IEEE Transactions on Smart Grid, Sept 2011, no.99, pp. 1-9)

[18] J.A.Taylor and A.Maitra, "Sensitivity Evaluations of Plug-in Electric Vehicle Charging on Distribution Service Transformer Insulation Life," (2011 Cigré International Symposium- The Electric Power System of the Future, Sept 2011, pp. 1-6)

[19] Report of European Distribution System Operators for Smart Grid on "Smart charging: integrating a large widespread of electric cars in electricity distribution grids," March 2018.

[20] P.Richardson et al., "Impact assessment of varying penetrations of electric vehicles on low voltage distribution systems," (2010 IEEE Power and Energy Society General Meeting, Jul 2010, pp. 25-29)

[21] F.J.Soares, J.A.P.Lopes and P.M.R.Almeida, "A Monte Carlo method to evaluate electric vehicles impacts in distribution networks," (2010 IEEE Conference on Innovative Technologies for an Efficient and Reliable Electricity Supply, Sept 2010, pp. 365-372)

[22] Robert Bass, Nicole Zimmerman, "Impacts of Electric Vehicle Charging on Electric Power Distribution Systems", Electrical and Computer Engineering Faculty Publications and Presentations, Sep 2013.

[23] AC Propulsion, "AC Propulsion Partners with BMW to build 500 Electric Vehicles ", (Nov 2008, pp. 1-4)

[24] E.C.Bentley et al., "The interactive effects of multiple EV chargers within a distribution network," (2010 IEEE Vehicle Power and Propulsion Conference, Sept 2010, pp. 1-6)

[25] Marjan Gjelaj, Chresten Træholt, Seyedmostafa Hashemi, Peter Bach Andersen, "Optimal Design of DC Fast-Charging Stations for EVs in Low Voltage Grids", Proceedings of 2017 IEEE Transportation Electrification Conference, 2017.

[26] Jorge Nájera Álvarez, Katarina Knezović, Mattia Marinelli, "Analysis and Comparison of Voltage Dependent Charging Strategies for Single-Phase Electric Vehicles Charging Strategies for Single-Phase Electric Vehicles", IEEE 2016.

[27] Dale Hall, Hongyang Cui, and Nic Lutsey, "Electric vehicle capitals: Accelerating the global transition to electric drive," published by ICCT, Oct 2018.

[28] "Maharashtra's Electric Vehicle and Related Infrastructure Policy-2018", Magnetic Maharashtra Convergence 2018.

[29] Draft version of "Delhi Electric Vehicle Policy-2018", Transport Department, GNCTD.

[30] UP Electric Vehicle manufacturing policy, 2018

[31] Draft version of "Telangana Electric Vehicle Policy", September 2017

[32] "Karnataka Electric Vehicle and Energy Storage Policy 2017", proceedings of Government of Karnataka, 2017

[33] The Draft Policy on EV for the State of Kerala, 2018

[34] Clarifications on charging infrastructure for EV with reference to the provisions of the Electricity Act, 2003, by Ministry of Power, 13th April 2018. https://powermin.nic.in/sites/default/files/webform/notices/Clarification_on_charging_infrastructure_for_Electric_Vehicles_with_reference_to_the_provisions_of_the_Electrcity_Act_2003.pdf

[35] "Charging infrastructure for Electric Vehicles – Guidelines and Standards" by Ministry of Power, 14th Dec 2018. https://powermin.nic.in/sites/default/files/webform/notices/scan0016%20%281%29.pdf

[36] Study on Impact of Electric Vehicles on the Grid, Forum of Regulators, September 2017, available at: http://www.forumofregulators.gov.in/Data/study/EV.pdf

[37] The Distribution Code - of Licensed Distribution Network Operators of Great Britain, http://www.dcode.org.uk/assets/uploads/D_Code_36_clean_181206.pdf

[38] The Electricity Safety, Quality and Continuity Regulations 2002, Available at : http://www.legislation.gov.uk/uksi/2002/2665/pdfs/uksi_20022665_en.pdf

[39] Power Quality Application Guide by Copper Development Association, Voltage Disturbances Standard EN 50160 "Voltage Characteristics in Public Distribution Systems", available at: http://copperalliance.org.uk/uploads/2018/03/542-standard-en-50160-voltage-characteristics-in.pdf

[40] Distribution Code, Issued by Distribution System Operator ESB Networks Limited, available at : https://www.esbnetworks.ie/docs/default-source/publications/distribution-code-v5-0.pdf?sfvrsn=6

[41] Electric Vehicles: The Barriers to Power System Integration, D. Hardman, A Rotheram, S Jupe, D Hawkins, Parsons Brinckerhoff, United Kingdom, CIGRE Symposium 2012.

[42] Report on "The China New Energy Vehicles Program Challenges and Opportunities," prepared by PRTM, April 2011.

[43] Electric Vehicle Conductive AC Charging System, AIS-138 (Part 1), available at, https://araiindia.com/hmr/Control/AIS/210201752832PMAIS138_Part1.pdf

[44] Image was clicked at BESCOM charging station with due permission from BESCOM

[45] DERC Regulations- http://www.derc.gov.in/regulations/dercregulations/Regulations%202017/DERC%20(Supply%20Code%20and%20Performance%20Standards)%20Regulations,%202017/Regulations%20-%2007.07.2017.pdf

[46] SAE International standards work, including communication protocols and connectors, fast charge, batteries

[47] Technical Report on "Transportation Electrification," EPRI, 2011

[48] "Standardization of protocol for charging infrastructure" by Government of India, Ministry of Heavy Industries & Public Enterprises and Department of Heavy Industry, 15th May 2017.

[49] Statistics of Vehicles in Delhi: http://delhi.gov.in/wps/wcm/connect/doit_transport/Transport/Home/Statistics

[50] Report on "INDIA leaps ahead: transformative mobility solutions for all," Niti Ayog, May 2017.

[51] C. Corchero, "European electric vehicle fleet: driving and charging behaviours," https://upcommons.upc.edu/bitstream/handle/2117/86393/Corchero_AEEE.pdf

[52] Idaho National Laboratory, "How Americans Charge their Electric Vehicles," https://avt.inl.gov/sites/default/files/pdf/arra/PluggedInSummaryReport.pdf

[53] Vitor Monteiro, J A Afonso, J C Ferreira and J L Afonso, "Vehicle Electrificatio: New Challenges and Opportunities for Smart Grids," Energies Journal, Dec 2018

[54] Manuele Bertoluzzo, Giuseppe Buja and Giovanni Pede, "Design considerations for fast AC battery chargers," World Electric Vehicle Journal Vol. 6, 2013.

[55] Building Codes, Link: https://economictimes.indiatimes.com/industry/auto/auto-news/ev-charging-stations-may-become-must-in-buildings-parking-lots/articleshow/66353793.cms

[56] NEC Article 625, “Electric Vehicle Charging and Supply Equipment Systems”

[57] SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler J1772_201001, Line: https://www.sae.org/standards/content/j1772_201001/

[58] News, Link: https://www.hindustantimes.com/mumbai/vehicles-pollute-more-than-industries-neeri-study/story-2sMt4fVJwo1Alji7lV7g7L.html

[59] Google Image, Link: https://www.google.com/search?rlz=1C1GCEU_enIN820IN820&biw=1366&bih=608&tbm=isch&sa=1&ei=KckAXZeDE_jfz7sP09uBuAk&q=uncontrolled+and+smart+charging+total+demand+of+multiple+households&oq=uncontrolled+and+smart+charging+total+demand+of+multiple+households&gs_l=img.3...18173.26810..27191...0.0..1.319.5695.0j32j3j1......0....1..gws-wiz-img.-ZrZGioiQJo#imgrc=1kvkcuN7czujeM:

[60] CIGRE Working group C6.20 Report on “Integration of Electric Vehicles in Electric Power Systems” Sep 2015.

[61] Draft version of “Delhi Electric Vehicle Policy-2018”, Transport Department, GNCTD.

[62] Statistics of Vehicles in Delhi: **http://delhi.gov.in/wps/wcm/connect/doit_transport/Transport/Home/Statistics**

[63] Report on “INDIA leaps ahead: transformative mobility solutions for all,” Niti Ayog, May 2017.

[64] C. Corchero, “European electric vehicle fleet: driving and charging behaviours,” **https://upcommons.upc.edu/bitstream/handle/2117/86393/Corchero_AEEE.pdf**

[65] Idaho National Laboratory, “How Americans Charge their Electric Vehicles,” **https://avt.inl.gov/sites/default/files/pdf/arra/PluggedInSummaryReport.pdf**

[66] State wise and year wise targets for installations of 40000 MWp Grid connected solar rooftop systems, MNRE, 2015. **https://mnre.gov.in/sites/default/files/webform/notices/State-wise-and-year-wise-target-for-installation-of-40000MWp-GCRT-systems_0.pdf**

[67] Solar Policy for Maharashtra, **https://www.itsmysun.com/rooftop-solar-applicable-policies/maharashtra/?category=Industrial&id=3**

[68] Jaspreet Singh, Sanjeev Singh and Amanpreet Singh, “Effect of Harmonics on Distribution Transformer Losses and Capacity,” IJETSR Journal, June 2017.

[69] Asaad A. Elmoudi, “Evaluation of Power System Harmonic Effects on Transformers,” PhD Thesis, Helsinki University of Technology, 2006.

[70] K. W. E. Cheng, B. P. Divakar, Hongjie Wu, Kai Ding and Ho Fai Ho, “Battery-Management System (BMS) and SOC Development for Electrical Vehicles,” IEEE Transactions on Vehicular Technology, Vol. 60, No. 1, January 2011.

[71] Ministry of Power, Government of India, “Charging Infrastructure for Electrical Vehicles – Guidelines and Standards-reg”, : **https://powermin.nic.in/sites/default/files/webform/notices/scan0016%20%281%29.pdf**

[72] Petition for Truing up upto FY 2017-18 and ARR & Tariff for FY 2019-20, https://www.bsesdelhi.com/documents/73527/2497782/Truing_up_for_expenses_upto_FY_2017_18_ARR_and_Tariff_for_FY_2019_20_Vol1.pdf/372f202c-413c-7adf-0a57-0312d81c3ee7

[73] Vishnuvardhan Telukunta, Janmejaya Pradhan, Anubha Agrawal, Manohar Singh and S G Srivani, “Protection Challenges Under Bulk Penetration of Renewable Energy Resources in Power Systems: A Review,” CSEE Journal of Power and Energy Systems, vol. 3, no. 4, December 2017

[74] http://www.megawatts.com.sg/wp-content/uploads/2018/03/Megawatts_EVChargingSystem.jpg

Annexure

12

Annexure

12.1 Data Statistics for Development of Scenarios

The following data statistics are used to project the EVs in BYPL region.

1. Total vehicles registered (IC+EV) in Delhi by 31-03-2018 [62]
2. Yearly addition of new vehicles in Delhi from 2013-14 to 2017-18 [62]
3. 5 years focus (till 2023) with 25% EV new sales target (across all vehicle segments) [61] [63]
4. For buses in Delhi, 50% EV new sales target [62]

BYPL utility data for selected 3 feeders is presented in Table 12.1.1.

Table 12.1.1: BYPL utility data for selected 3 feeders

Feeder Name	# of Residential connections	# of Commercial connections	# of Industrial connections	# of Institutional connections	# of Other connections	Total number of connections
Janta Colony	3,718	3	-	46	-	3,767 (0.22%)*
Arya Samaj	4,889	69	2	17	-	4,977 (0.29%)*
MVR Sadar	1,944	70	8	5	-	2,027 (0.12%)*
Total BYPL	**13,28,123**	**3,89,084**	**7,730**	**4,550**	**382**	**17,29,869 (100%)**

*Percentage of connections in each feeder with respect to total number of connections in BYPL.

For better understanding of the methodology, the calculation of total EV numbers is approached in 3 stages as presented in Figure 12.1.1.

1. For Delhi – From the historical data of total vehicles registered in Delhi, total number of vehicles for future years are projected.
2. For BYPL region – BYPL is one of the 5 DISCOMs in Delhi. From the projected data of total Delhi vehicles for future, it is assumed that 25% of all vehicles in Delhi will come under BYPL region, which is further considered for projection of EVs in selected feeders.
3. For selected 3 feeders – The % contribution of electric connections of selected feeder is taken as reference and corresponding % of EVs are considered under each feeder.

Example- Janta colony feeder contributes to 0.22% of electric connections of BYPL region, hence 0.22% of EVs in BYPL region is considered in Janta colony feeder for each year.

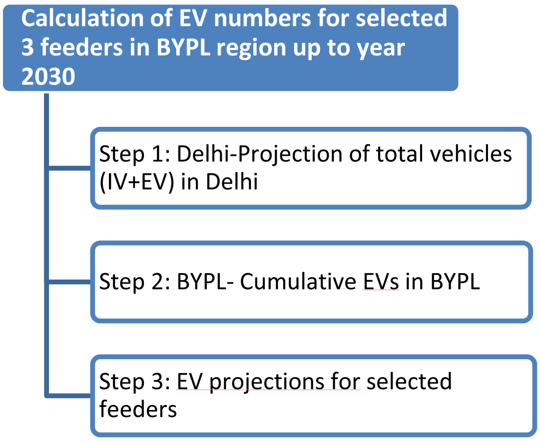


Figure 12.1.1: Steps involved in calculating EVs in selected feeders

12.1.1 Stage 1: Statistics at City Level: Delhi

The process adopted to arrive the total vehicles (ICE+EV) are presented in Figure 12.1.2.

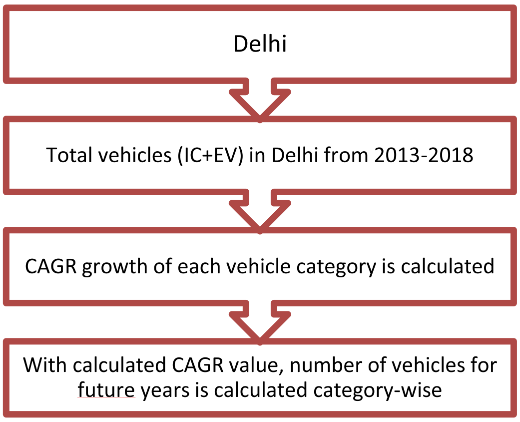


Figure 12.1.2: Process of calculating total vehicles in Delhi

Total Vehicles on Road in Delhi as on 31-03-2018 is given in Table 12.1.2

Table 12.1.2: Total Vehicles on Road in Delhi as on 31-03-2018

Type of vehicle registered	Nos.
Agricultural Tractor	217
Ambulance	2330
Bus	23829
Camper Van/trailer	1
Cash Van	49
Construction Equipment Vehicle	3
Crane Mounted Vehicle	256
Educational Institution Bus	2

Type of vehicle registered	Nos.
e-Rickshaw (P)	46598
e-Rickshaw with cart (G)	610
Fire Fighting Vehicle	10
Goods carrier	153389
Invalid Carriage	723
Luxury Cab	1464
Maxi Cab	24854
M-Cycle/Scooter	6957223
M-Cycle/Soocter-with side car	1001
Mobile Workshop	19
Moped	119854
Motor Cab	107650
Motor Car	3132839
Motor Cycle/Scooter - With Trailer	1
Motorised Cycle (CC >25cc)	16
Private Service Vehicle (Individual Use)	12
Omini Bus	42
Omini Bus (Private Use)	4
Recovery vehicle	295
Three Wheeler (Goods)	69699
Three Wheeler (Passenger)	111674
Three Wheeler (Personal)	53
Tractor (commercial)	2051
Total	**1,07,56,768**

Yearly addition of new vehicles in Delhi from 2013-14 to 2017-18 is presented in Table 12.1.3.

Table 12.1.3: Yearly addition of new vehicles in Delhi from 2013-14 to 2017-18

Vehicle registered	2013-14	2014-15	2015-16	2016-17	2017-18
	No's	No's	No's	No's	No's
Agricultural Tractor	25	74	82	28	6
Ambulance	142	76	73	63	62
Bus	1,254	1,023	702	877	591
Camper Van/trailer					
Cash Van	0	0	0	36	15
Construction Equipment Vehicle					
Crane Mounted Vehicle	42	21	61	0	
Educational Institution Bus	0	0	0	2	
e-Rickshaw (P)	0	0	8557	20566	16842
e-Rickshaw with cart (G)	0	0	0	48	553
Fire Fighting Vehicle	0	0	0	9	

Vehicle registered	2013-14	2014-15	2015-16	2016-17	2017-18
	No's	No's	No's	No's	No's
Goods carrier	11465	13824	14944	11503	15400
Invalid Carriage	40	60	89	91	97
Luxury Cab	363	452	316	126	1
Maxi Cab	1560	1847	1888	879	452
M-Cycle/Scooter	337835	372462	431184	443417	476691
M-Cycle/Scooter-with side car	26	27	69	70	79
Mobile Workshop	0	10	8	0	
Moped	5754	6008	4273	5361	4745
Motor Cab	5841	9509	24128	26836	8259
Motor Car	157789	169813	171520	157513	181488
Motor Cycle/Scooter - With Trailer					3
Motorised Cycle (CC >25cc)	0	0	2	5	
Private Service Vehicle (Individual Use)	0	0	3	0	
Omini Bus	0	0	0	19	7
Omini Bus (Private Use)					
Recovery vehicle	5	2	10	31	
Three Wheeler (Goods)	2325	2647	16014	3921	1117
Three Wheeler (Passenger)	4955	10486	9	9871	14110
Three Wheeler (Personal)	4	8	0	3	1
Tractor (commercial)	141	0	0	0	
Total vehicles registered	**5,29,566**	**5,88,349**	**6,73,932**	**6,81,275**	**7,20,519**

For analysis, vehicles are categorized as 2 Wheelers (2W), 3 Wheeler Passenger Vehicles (3W-PV), 3 Wheeler Commercial Vehicles (3W-CV), 4 Wheeler Passenger Vehicles (4W-PV), 4 Wheeler Commercial Vehicles (4W-CV) and Bus. Different vehicles registered are segregated under the considered category for the study as shown in Table 12.1.4.

Table 12.1.4: Segregation of vehicles to vehicle categories considered

Vehicle category	Vehicles considered*
2W	M-Cycle/Scooter, Moped, M-Cycle/Scooter-with side car
3W - PV	3W personal, 3W passenger and e-rickshaws
3W-CV	3W goods
4W - PV	Motor car
4W - CV	Motor cabs, luxury cabs and maxi cabs
Bus	normal buses, omni bus, educational institution buses

* *Vehicles not considered under any category- Agricultural Tractor, Ambulance, Cash Van, Crane Mounted Vehicle, Fire Fighting Vehicle, Goods carrier, Invalid Carriage, Mobile Workshop, Private Service Vehicle (Individual Use), Recovery vehicle, Tractor (commercial).*

Yearly addition of new vehicles is segregated as per vehicles category is shown in Table 12.1.4 and Table 12.1.5.

Table 12.1.5: Segregation of yearly addition of new vehicles in Delhi from 2013-14 to 2017-18

New Vehicles Addition	2013-14	2014-15	2015-16	2016-17	2017-18
No.	No.	No.	No.	No.	
2W	3,43,615	3,78,497	4,35,528	4,48,853	4,81,515
3W - PV	4,959	10,494	8,566	30,440	30,953
3W - CV	2,325	2,647	16,014	3,921	1,117
4W - PV	1,57,789	1,69,813	1,71,520	1,57,513	1,81,488
4W - CV	7,764	11,808	26,332	27,841	8,712
Bus	1,254	1,023	702	898	598
Total	**5,17,706**	**5,74,282**	**6,58,662**	**6,69,466**	**7,04,383**

Vehicles on road for respective previous year (Table 12.1.6) are calculated by subtracting the new vehicle additions for respective year (Table 12.1.5) from total available vehicles on the road (Table 12.1.2). The cumulative vehicles on road are calculated from the above method for years starting from 2013 to 2017. Total cumulative number of vehicles registered in Delhi from year 2013 to 2018 is presented in Table 12.1.6. From the total cumulative vehicles, CAGR growth for each vehicle category is calculated. With the calculated CAGR, total number of vehicles is projected for future years for each vehicle category.

Table 12.1.6: Year wise Cumulative vehicles on Road in Delhi

Vehicle category	2013	2014	2015	2016	2017	2018	CAGR
	No's	**No's**	**No's**	**No's**	**No's**	**No's**	**%**
2W	49,90,070	53,33,685	57,12,182	61,47,710	65,96,563	70,78,078	6.00%
3W - PV	73,523	78,482	88,976	97,542	1,27,982	1,58,935	13.71%
3W - CV	43,675	46,000	48,647	64,661	68,582	69,699	8.10%
4W - PV	22,94,716	24,52,505	26,22,318	27,93,838	29,51,351	31,32,839	5.33%
4W - CV	51,560	59,324	71,132	97,464	1,25,305	1,34,017	17.26%
Bus	19,400	20,654	21,677	22,379	23,277	23,875	3.52%
Total	**74,72,944**	**79,90,650**	**85,64,932**	**92,23,594**	**98,93,060**	**1,05,97,443**	**5.99%**

With calculated CAGR (Table 12.1.6), cumulative vehicles on road in Delhi is projected from years 2019 to 2030. Projected vehicles on road in Delhi are presented in Table 12.1.7. Total cumulative vehicles projected for Delhi up to the year 2030 (Table 12.1.7) is considered to calculate the number of EVs in BYPL region up to the year 2030.

Table 12.1.7: Projected vehicles on road in Delhi up to year 2030

Vehicle	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
category	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**
2W	75,02,686	79,52,767	84,29,847	89,35,547	94,71,584	1,00,39,777	1,06,42,055	1,12,80,464	1,19,57,170	1,26,74,471	1,34,34,803	1,42,40,747
3W - PV	3,34,127	3,54,171	3,75,418	3,97,939	4,21,811	4,47,115	4,73,937	5,02,368	5,32,505	5,64,449	5,98,310	6,34,202
3W - CV	75,346	79,866	84,657	89,735	95,118	1,00,824	1,06,873	1,13,284	1,20,080	1,27,283	1,34,919	1,43,013
4W - PV	32,99,688	34,97,634	37,07,455	39,29,862	41,65,611	44,15,503	46,80,386	49,61,158	52,58,774	55,74,244	59,08,639	62,63,093
4W - CV	1,57,145	1,66,572	1,76,565	1,87,157	1,98,384	2,10,285	2,22,900	2,36,271	2,50,445	2,65,469	2,81,394	2,98,275
Bus	25,715	27,258	28,893	30,626	32,464	34,411	36,476	38,664	40,983	43,442	46,048	48,810
Total	**1,13,94,708**	**1,20,78,268**	**1,28,02,834**	**1,35,70,866**	**1,43,84,972**	**1,52,47,915**	**1,61,62,626**	**1,71,32,209**	**1,81,59,957**	**1,92,49,359**	**2,04,04,113**	**2,16,28,140**

12.1.2 Stage 2: Statistics at BYPL Region

The process adopted to arrive the total vehicles (ICE+EV) are presented in Figure 12.1.3.

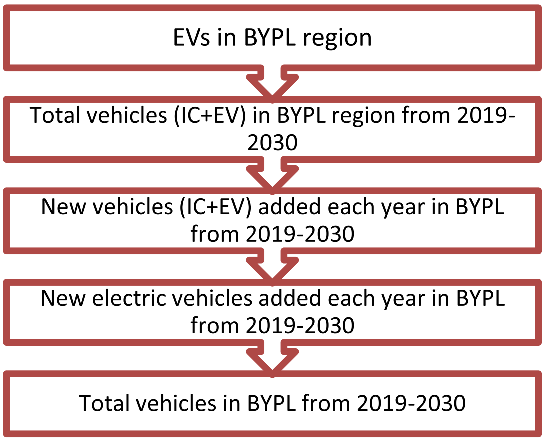


Figure 12.1.3: Process of calculating total EVs in BYPL

BYPL is one of the 5 DISCOMS in Delhi and 25% of total vehicles in Delhi are in BYPL region. Hence 25% of cumulative vehicles projected for each year for Delhi are considered for BYPL region as furnished in Table 12.1.8.

Vehicles added each year in BYPL region is obtained by simple subtraction of cumulative vehicles available each year with the vehicles on road in previous year in BYPL region. New vehicles added in BYPL each year is furnished in Table 12.1.9.

EV policy [61] states that new vehicle sales of all vehicle categories will be 25% by the year 2023. Transport department of Delhi issued a circular on 27.11.2018 stating all new sales of buses in Delhi will be 50% [62]. Electric vehicle sales with respect to total vehicles sales in Delhi of each vehicle category for future years are assumed in order to match with the EV policy (2W, 3W-PV, 3W-CV, 4W-PV, 4W-CV) and Delhi transport department circular (for bus). The % EV sales assumed for each vehicle category for future years is furnished in Table 12.1.10.

Total EVs added each year in BYPL is calculated based on new vehicles added in BYPL (Table 12.1.9) and % of EV sales in new vehicles (Table 12.1.10) and presented in Table 12.1.11.

New EVs added each year is added to cumulative EVs in BYPL region to obtain cumulative EVs in BYPL up to 2030. Cumulative EVs in BYPL is furnished in Table 12.1.12.

Table 12.1.8: Number of vehicles under BYPL region projected for future years

Vehicle category	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
	No.	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**
2W	17,69,520	18,75,672	19,88,192	21,07,462	22,33,887	23,67,896	25,09,944	26,60,514	28,20,116	29,89,292	31,68,618	33,58,701	35,60,187
3W - PV	39,734	83,532	88,543	93,854	99,485	1,05,453	1,11,779	1,18,484	1,25,592	1,33,126	1,41,112	1,49,578	1,58,551
3W - CV	17,425	18,836	19,966	21,164	22,434	23,780	25,206	26,718	28,321	30,020	31,821	33,730	35,753
4W - PV	7,83,210	8,24,922	8,74,409	9,26,864	9,82,465	10,41,403	11,03,876	11,70,096	12,40,290	13,14,694	13,93,561	14,77,160	15,65,773
4W - CV	33,504	39,286	41,643	44,141	46,789	49,596	52,571	55,725	59,068	62,611	66,367	70,349	74,569
Bus	5.969	6,429	6,815	7,223	7,657	8,116	8,603	9,119	9,666	10,246	10,860	11,512	12,202
Total	**26,49,361**	**28,48,677**	**30,19,567**	**32,00,709**	**33,92,717**	**35,96,243**	**38,11,979**	**40,40,656**	**42,83,052**	**45,39,989**	**48,12,340**	**51,01,028**	**54,07,035**

Table 12.1.9: New vehicles added in BYPL each year

Vehicle category	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.
2W	1,06,152*	1,12,520	1,19,270	1,26,425	1,34,009	1,42,048	1,50,570	1,59,602	1,69,177	1,79,325	1,90,083	2,01,486
3W - PV	43,798	5,011	5,312	5,630	5,968	6,326	6,706	7,108	7,534	7,986	8,465	8,973
3W - CV	1,412	1,130	1,198	1,270	1,346	1,427	1,512	1,603	1,699	1,801	1,909	2,023
4W - PV	41,712	49,486	52,455	55,602	58,937	62,473	66,221	70,193	74,404	78,867	83,599	88,614
4W - CV	5,782	2,357	2,498	2,648	2,807	2,975	3,154	3,343	3,543	3,756	3,981	4,220
Bus	460	386	409	433	459	487	516	547	580	615	652	691
Total	**1,99,316**	**1,70,890**	**1,81,141**	**1,92,008**	**2,03,526**	**2,15,736**	**2,28,678**	**2,42,396**	**2,56,937**	**2,72,350**	**2,88,689**	**3,06,007**

**Total 2W added in BYPL, 1,06,152 = 18,75,672-17,69,520 (cumulative vehicles in BYPL in 2019- cumulative vehicles in BYPL in 2018), similarly for all vehicle categories for future years*

Table 12.1.10: % EV sales assumed for each vehicle category for future years

Vehicle category	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
2W	1%*	3%	5%	10%	15%	25%	27%	30%	33%	35%	37%	40%	40%
3W - PV	5%	10%	15%	20%	25%	25%	30%	40%	50%	60%	70%	80%	100%
3W - CV	0%	3%	5%	10%	15%	25%	30%	35%	40%	45%	50%	60%	70%
4W - PV	1%	1%	5%	10%	15%	25%	25%	25%	26%	27%	28%	29%	30%
4W - CV	1%	5%	10%	15%	20%	25%	30%	40%	50%	60%	70%	80%	100%
Bus	0%	5%	10%	15%	20%	50%	55%	60%	65%	70%	80%	90%	100%

**1% of all 2W sales in 2018 are considered as 2W EV, similarly for all vehicle categories for future years*

Table 12.1.11: Number of EVs added each year in BYPL region

Vehicle category	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.
2W	3,185	5,626	11,927	18,964	33,502	38,353	45,171	52,669	59,212	66,350	76,033	80,594
3W - PV	4,380	752	1,062	1,408	1,492	1,898	2,682	3,554	4,521	5,590	6,772	8,973
3W - CV	42	56	120	190	336	428	529	641	765	900	1,145	1,416
4W - PV	417	2,474	5,246	8,340	14,734	15,618	16,555	18,250	20,089	22,083	24,244	26,584
4W - CV	289	236	375	530	702	893	1,261	1,671	2,126	2,629	3,185	4,220
Bus	23	39	61	87	230	268	310	356	406	492	586	691
Total	**8,336**	**9,183**	**18,791**	**29,518**	**50,996**	**57,457**	**66,509**	**77,141**	**87,118**	**98,045**	**1,11,966**	**1,22,479**

Table 12.1.12: Cumulative EVs in BYPL

Vehicle category	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.
2W	17,695*	20,880	26,506	38,433	57,397	90,899	129,252	174,423	227,091	286,303	352,654	428,687	509,281
3W - PV	50,000**	54,380	55,131	56,194	57,601	59,093	60,991	63,673	67,227	71,748	77,338	84,110	93,083
3W - CV	0	42	99	219	409	746	1,173	1,703	2,344	3,108	4,009	5,154	6,571
4W - PV	7,832	8,249	10,724	15,969	24,309	39,044	54,662	71,217	89,467	109,556	131,639	155,883	182,467
4W - CV	361	650	886	1,261	1,790	2,492	3,384	4,646	6,317	8,443	11,073	14,258	18,478
Bus	0	23	62	123	210	439	707	1,017	1,372	1,778	2,270	2,856	3,547
Total	**75,888**	**84,224**	**93,407**	**112,198**	**141,716**	**192,712**	**250,170**	**316,678**	**393,819**	**480,937**	**578,982**	**690,948**	**813,427**

**for 2018, cumulative EV in BYPL is obtained from Table 12.1.8 and*

Table 8.1.10 *(1% of* 17,69,520 = 17695), similarly *for all vehicle categories*

*#Cumulative EV 2W in 2019, 20,880=17695+3185 (Cumulative EV 2W in 2019 + EV 2W added in 2019 (*Table 8.1.11*)), similarly for all vehicles for future years*

**50,000 E-Rickshaw's are already in service under BYPL and the same has been considered for the simulation.

12.1.3 Stage 3: EV Projections for Selected 3 Feeders

Total EVs under each feeder is considered in proportion to the number of connections in the feeder with respect to total BYPL connections as presented in Figure 12.1.4.

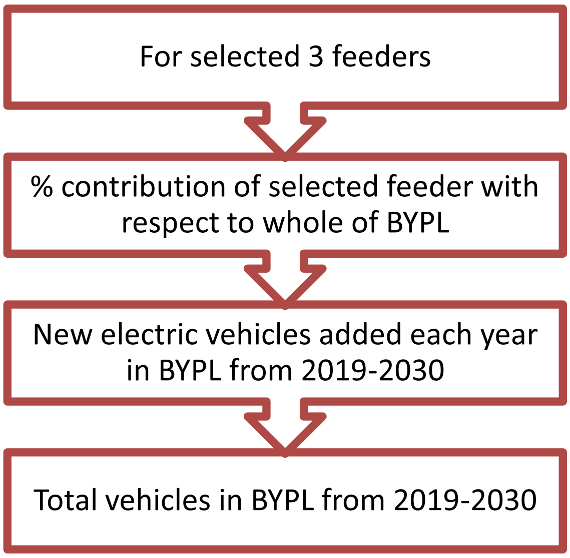


Figure 12.1.4: Process of calculating total EVs selected 3 feeders

12.1.3.1 Janta Colony Feeder

Contribution of Janta colony feeder with respect to BYPL region in terms of electrical connections is 0.22% as presented in Table 12.1.13. Total EVs added each year in Janta colony feeder is considered 0.22% of total EVs added in BYPL region (Table 12.1.11). Yearly new EVs addition in Janta colony feeder is shown in Table 12.1.14.

Table 12.1.13: Number of electric connections in Janta colony feeder

Feeder Name	# of Residential connections	# of Commercial connections	# of Industrial connections	# of Institutional connections	# of Other connections	Total number of connections
Janta Colony	3,718	3	-	46	-	3,767 (0.22%)*
Total BYPL	**13,28,123**	**3,89,084**	**7,730**	**4,550**	**382**	**17,29,869 (100%)**

Table 12.1.14: Yearly EV Addition in Janta colony

Vehicle category	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
	No.	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**
2W	7	12	26	41	73	84	98	115	129	144	166	176
3W - PV	10	2	2	3	3	4	6	8	10	12	15	20
3W - CV	0	0	0	0	1	1	1	1	2	2	2	3
4W - PV	1	5	11	18	32	34	36	40	44	48	53	58
4W - CV	1	1	1	1	2	2	3	4	5	6	7	9
Total	**18**	**20**	**41**	**64**	**111**	**125**	**145**	**168**	**190**	**214**	**244**	**267**

Table 12.1.15: Cumulative number of EV in Janta colony

Vehicle category	2018*	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.
2W	39	45	58	84	125	198	281	380	495	623	768	934	1,109
3W - PV	109	118	120	122	125	129	133	139	146	156	168	183	203
3W - CV	-	0	0	0	1	2	3	4	5	7	9	11	14
4W - PV	17	18	23	35	53	85	119	155	195	239	287	339	397
4W - CV	1	1	2	3	4	5	7	10	14	18	24	31	40
Bus	-	0	0	0	0	1	2	2	3	4	5	6	8
Total	165	183	203	244	309	420	545	690	858	1,047	1,264	1,505	1,771

for 2018, cumulative EV in Janta colony feeder is obtained by considering 0.22% of cumulative EVs in BYPL (Table 12.1.12)

12.1.3.2 Arya Samaj Feeder

Contribution of Arya Samaj feeder with respect to BYPL region in terms of electrical connections is 0.29% as presented in Table 12.1.16. Total EVs added each year in Janta colony feeder is considered 0.29% of total EVs added in BYPL region (Table 12.1.11). Yearly new EVs addition in Janta colony feeder is shown in Table 12.1.17.

Table 12.1.16: Number of electric connections in Arya Samaj feeder

Feeder Name	# of Residential connections	# of Commercial connections	# of Industrial connections	# of Institutional connections	# of Other connections	Total number of connections
Arya Samaj	4,889	69	2	17	-	4,977 (0.29%)*
Total BYPL	**13,28,123**	**3,89,084**	**7,730**	**4,550**	**382**	**17,29,869 (100%)**

Table 12.1.17: Yearly EV Addition in Arya Samaj Feeder

Vehicle category	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
	No.	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**
2W	9	16	34	55	96	110	130	152	170	191	219	232
3W - PV	13	2	3	4	4	5	8	10	13	16	19	26
3W - CV	0	0	0	1	1	1	2	2	2	3	3	4
4W - PV	1	7	15	24	42	45	48	53	58	64	70	76
4W - CV	1	1	1	2	2	3	4	5	6	8	9	12
Bus	0	0	0	0	1	1	1	1	1	1	2	2
Total	**24**	**26**	**54**	**85**	**147**	**165**	**191**	**222**	**251**	**282**	**322**	**352**

Table 12.1.18: Cumulative number of EVs in Arya Samaj Feeder

Vehicle category	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.
2W	51	60	76	111	165	262	372	502	653	824	1,015	1,233	1,465
3W - PV	144	156	159	162	166	170	175	183	193	206	223	242	268
3W - CV	-	0	0	1	1	2	3	5	7	9	12	15	19
4W - PV	23	24	31	46	70	112	157	205	257	315	379	448	525
4W - CV	1	2	3	4	5	7	10	13	18	24	32	41	53
Bus	-	0	0	0	1	1	2	3	4	5	7	8	10
Total	**218**	**242**	**269**	**323**	**408**	**554**	**720**	**911**	**1,133**	**1,384**	**1,666**	**1,988**	**2,340**

**for 2018, cumulative EV in Arya Samaj feeder is obtained by considering 0.29% of cumulative EVs in BYPL (Table 12.1.12)*

12.1.3.3 MVR Sadar Feeder

Contribution of MVR Sadar colony feeder with respect to BYPL region in terms of electrical connections is 0.12% as presented in Table 12.1.19. Total EVs added each year in Janta colony feeder is considered as 0.12% of total EVs added in BYPL region (Table 12.1.11). Yearly new EVs addition in Janta colony feeder is shown in Table 12.1.20.

Table 12.1.19: Number of electric connections in MVR Sadar feeder

Feeder Name	# of Residential onnections	# of Commercial connections	# of Industrial connections	# of Institutional connections	# of Other connections	Total number of connections
MVR Sadar	1,944	70	8	5	-	2,027 (0.12%)*
Total BYPL	**13,28,123**	**3,89,084**	**7,730**	**4,550**	**382**	**17,29,869 (100%)**

Table 12.1.20: Yearly EV Addition in MVR Sadar Feeder

Vehicle category	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.
2W	4	7	14	22	39	45	53	62	69	78	89	94
3W - PV	5	1	1	2	2	2	3	4	5	7	8	11
3W - CV	0	0	0	0	0	1	1	1	1	1	1	2
4W - PV	0	3	6	10	17	18	19	21	24	26	28	31
4W - CV	0	0	0	1	1	1	1	2	2	3	4	5
Bus	0	0	0	0	0	0	0	0	0	1	1	1
Total	**10**	**11**	**22**	**35**	**60**	**67**	**78**	**90**	**102**	**115**	**131**	**144**

Table 12.1.21: Cumulative number of EV in MVR Sadar Feeder

Vehicle category	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.
2W	21	24	31	45	67	107	151	204	266	335	413	502	597
3W - PV	59	64	65	66	67	69	71	75	79	84	91	99	109
3W - CV	-	0	0	0	0	1	1	2	3	4	5	6	8
4W - PV	9	10	13	19	28	46	64	83	105	128	154	183	214
4W - CV	0	1	1	1	2	3	4	5	7	10	13	17	22
Bus	-	0	0	0	0	1	1	1	2	2	3	3	4
Total	**89**	**99**	**109**	**131**	**166**	**226**	**293**	**371**	**461**	**564**	**678**	**810**	**953**

**for 2018, cumulative EV in MVR Sadar feeder is obtained by considering 0.12% of cumulative EVs in BYPL (Table 12.1.12)*

12.2 Methodology to Calculate the Number of Charges Occurring Under Each Selected Feeder per Day

Number of vehicles under each feeder is calculated up to year 2030. The charging pattern of different vehicle categories charging at different charging locations throughout the day is presented in this section.

Following parameters are considered to calculate the number of charges (total number of times electric vehicles plugged in and charged) in a day under each feeder.

1. Average battery size for each vehicle category
2. Average vehicle efficiency
3. Average km run/day for each vehicle category
4. Distance per charge per vehicle (kms)
5. Charging cycles distribution over a year
6. Average Full Charging Time for EV battery in hours
7. Average charging rate of EV at different charging locations (C)

Based on the existing EV battery sizes available in the Indian market, average battery sizes for different vehicle categories are considered. Average battery sizes considered for each vehicle category is furnished in Table 12.2.1. For the year 2030, higher battery capacities of vehicles are considered in the simulation studies to incorporate technology advancements in EV battery by the year 2030. Average battery sizes considered for each vehicle category for the year 2030 is furnished in Table 12.2.2

Table 12.2.1: Average battery sizes considered for each vehicle category as per existing trends in India

Vehicle category	Battery size in kWh
2W	1.5
3W – PV	4
3W - CV	7
4W - PV	15
4W - CV	15
Bus	120

Table 12.2.2: Average battery sizes considered for each vehicle category for the year 2030

Vehicle category	Battery size in kWh
2W	4
3W – PV	9
3W - CV	9
4W - PV	80
4W - CV	80
Bus	250

For the vehicle categories considered, average EV efficiency, average km run per day are assumed and the same is presented in Table 12.2.3. Initial SOC of all vehicle categories is considered to be 25% and the ranges of the vehicles are considered as per the existing trends. Number of charges for each vehicle category is calculated based on these parameters. A swap factor of 1.2 is considered while calculating the number of charges for swapping batteries.

For the year 2030, the initial SOC, average km run per day are assumed to remain same as previous case. Corresponding calculations are presented in Table 12.2.3

Table 12.2.3: Basic assumptions with respect to EV batteries for existing trend in India

Vehicle category	Average vehicle efficiency		Avg. km run		Range of the vehicle	Initial SOC of the vehicle	Range left	Plug-in after X km	# of charges per year per vehicle	
	Wh/ km	km/ kWh	kms/ day	kms/ year	(km)	(%)	km	km	If Integrated	If Swapping only
2W	20	50	20	7,300	75	25	19	56	130	156
3W – PV	50	20	100	36,500	80	25	20	60	608	730
3W - CV	70	14	80	29,200	100	25	25	75	389	467
4W - PV	130	8	34.3	12,520	115	25	29	87	145	174
4W - CV	130	8	210	76,650	115	25	29	87	886	1063
Bus	1000	1	200	73,000	120	25	30	90	811	973

Table 12.2.4: Basic assumptions with respect to EV batteries for the year 2030

Vehicle category	Average vehicle efficiency		Avg. km run		Range of the vehicle	Initial SOC of the vehicle	Range left	Plug-in after X km	# of charges per year per vehicle	
	Wh/ km	km/ kWh	kms/ day	kms/ year	(km)	(%)	km	km	If Integrated	If Swapping only
2W	20	50	20	7,300	150	25	38	113	65	78
3W – PV	50	20	100	36,500	100	25	25	75	487	584
3W - CV	70	14	80	29,200	100	25	25	75	389	467
4W - PV	130	8	34.3	12,520	350	25	88	263	48	57
4W - CV	130	8	210	76,650	350	25	88	263	292	350
Bus	1000	1	200	73,000	250	25	63	188	389	467

Based on reported study [65], the % of times the total charges occurring different charging locations are considered for 4W-PV and 2W. For other vehicles, based on the most likely charging pattern that would occur in India is considered and the percentage of charges are distributed as presented in Table 12.2.5.

Table 12.2.5: EV annual charges distribution to location of charging

Vehicle category	Home charging	Office/Work charging	Public charging Station	Mall/ Parking charging	Dedicated charging	Battery swapping
2W	65.00%	32.00%	1.50%	1.50%	0.00%	0.00%
3W - PV	14.00%	0.00%	19.00%	2.00%	15.00%	50.00%
3W - CV	14.00%	0.00%	34.00%	2.00%	20.00%	30.00%
4W - PV	65.00%	32.00%	1.50%	1.50%	0.00%	0.00%
4W - CV	14.00%	2.25%	32.50%	1.25%	50.00%	0.00%
Bus	0.00%	0.00%	20.00%	0.00%	80.00%	0.00%

With the average EV battery sizes considered, the time taken to charge the EV at different charging locations is presented in Table 12.2.6.

Table 12.2.6: Average Full Charging Time in hours

Vehicle category	Home charging	Office/Work charging	Public charging	Mall/ Parking charging	Dedicated charging	Swapping
	Home AC chargers	**Slow AC/DC chargers**	**Slow/Fast DC chargers**	**Slow DC chargers**	**Slow/Fast DC Chargers**	**Slow DC chargers**
	Hrs.	**Hrs**	**Hrs**	**Hrs**	**Hrs**	**Hrs**
2W	5	5	1	1	0.75	2
3W - PV	6	-	0.75	1.50	0.75	2
3W - CV	6	-	0.75	1.50	0.75	2
4W - PV	8	8	0.75	1.50	0.75	2
4W - CV	8	8	0.50	1.50	0.50	2
Bus	-	-	2	-	2	2

With the average EV battery sizes considered and the time taken to charge the EV at different charging locations, rate of charge of (C) of EV charger at various locations is calculated as shown in Table 12.2.7.

Table 12.2.7: Average charging rate (C) of EV at different charging locations

Vehicle category	Home charging	Office/Work charging	Public charging	Mall/ Parking charging	Dedicated charging	Swapping
	Home AC chargers	**Slow AC/DC chargers**	**Slow/Fast DC chargers**	**Slow DC chargers**	**Slow/Fast DC Chargers**	**Slow DC chargers**
	(C)	(C)	(C)	(C)	(C)	(C)
2W	0.20	0.20	1.00	1.00	1.33	0.50
3W - PV	0.17	-	1.33	0.67	1.33	0.50
3W - CV	0.17	-	1.33	0.67	1.33	0.50
4W - PV	0.13	0.13	1.33	0.67	1.33	0.50
4W - CV	0.13	0.13	2.00	0.67	2.00	0.50
Bus	-	-	0.50	-	0.50	0.50

From an European study [64] conducted over a period of three years, from 2011 to 2013, where more than 1,40,000 trips and 2,30,000 charging events were recorded, average plug in percentage of electric vehicles is considered for Home charging, office/work charging, mall/parking charging and public charging as shown in

Table 12.2.8. Public charging has been considered in the simulation study with no special focus on swapping considering the charging station can be used for battery swapping purpose based on the number charging ports available & its capacity at charging station.

Table 12.2.8: Distribution of Plug-in of EV at different point of day at different charging locations

Time Slots	Hour of the day	Home charging	Office/Work charging	Mall/ Parking charging	Public charging	Dedicated charging	Swapping
TS1	00:00	3.00%	0.50%	2.00%	2.00%	5.00%	10.00%
TS2	01:00	2.00%	0.50%	0.50%	0.50%	5.00%	10.00%
TS3	02:00	3.75%	0.00%	1.50%	1.25%	5.00%	10.00%
TS4	03:00	0.00%	0.00%	0.75%	1.00%	5.00%	10.00%
TS5	04:00	0.00%	0.00%	1.25%	1.25%	5.00%	10.00%
TS6	05:00	0.50%	1.00%	0.75%	1.00%	5.00%	10.00%
TS7	06:00	1.00%	2.00%	2.25%	2.25%	2.50%	5.00%
TS8	07:00	2.00%	7.00%	2.50%	2.50%	2.50%	5.00%
TS9	08:00	4.00%	14.00%	2.25%	2.25%	2.50%	0.00%
TS10	09:00	3.50%	8.00%	3.25%	3.00%	2.50%	0.00%
TS11	10:00	4.00%	5.50%	3.75%	3.75%	5.00%	0.00%
TS12	11:00	3.25%	6.00%	6.00%	6.00%	5.00%	0.00%
TS13	12:00	3.75%	7.00%	8.50%	8.50%	10.00%	5.00%
TS14	13:00	4.00%	6.50%	5.50%	5.00%	10.00%	5.00%
TS15	14:00	4.75%	11.00%	6.00%	6.00%	2.50%	5.00%
TS16	15:00	4.00%	8.00%	5.75%	6.00%	2.50%	5.00%
TS17	16:00	5.50%	7.00%	6.25%	6.50%	2.50%	0.00%
TS18	17:00	7.00%	3.00%	5.75%	6.00%	2.50%	0.00%
TS19	18:00	9.75%	2.00%	6.00%	6.50%	2.50%	0.00%
TS20	19:00	10.25%	1.00%	4.75%	4.75%	2.50%	0.00%
TS21	20:00	9.00%	1.00%	6.25%	6.00%	2.50%	0.00%
TS22	21:00	6.00%	8.00%	7.50%	7.50%	2.50%	0.00%
TS23	22:00	5.00%	0.50%	7.00%	6.50%	5.00%	5.00%
TS24	23:00	4.00%	0.50%	4.00%	4.00%	5.00%	5.00%
Total		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

12.3 Janta Colony: Simulations for 2023 and 2019

12.3.1 Janta Colony: DT Graphs for Case2B

Case2B:

Percentage loading of selected distribution transformers with EV loads and solar generation are presented in Figure 12.3.1 to Figure 12.3.4. Similar observations of previous case study are observed from the simulation results.

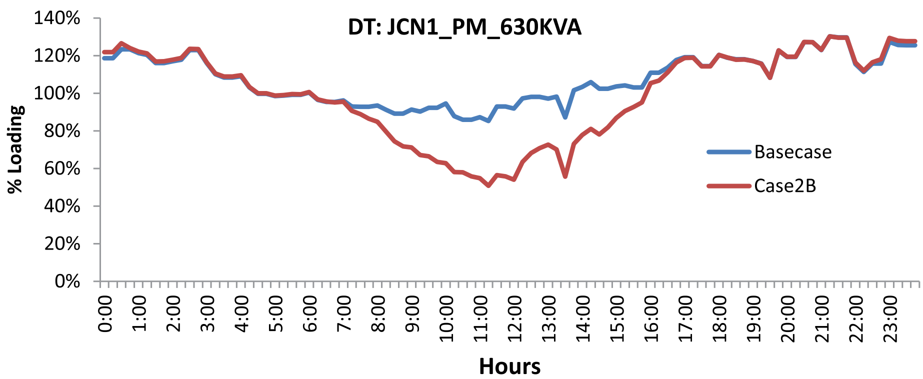


Figure 12.3.1: Transformer % loading of JCN1_PL_630KVA

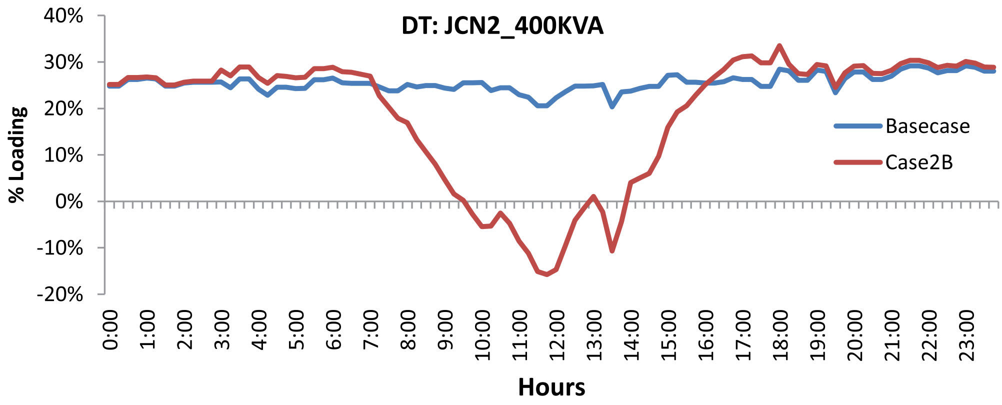


Figure 12.3.2: Transformer % loading of JCN2_400KVA

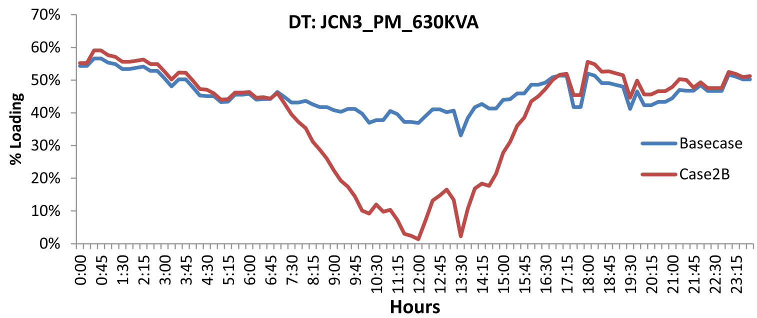


Figure 12.3.3: Transformer % loading of JCN3_PM_630KVA

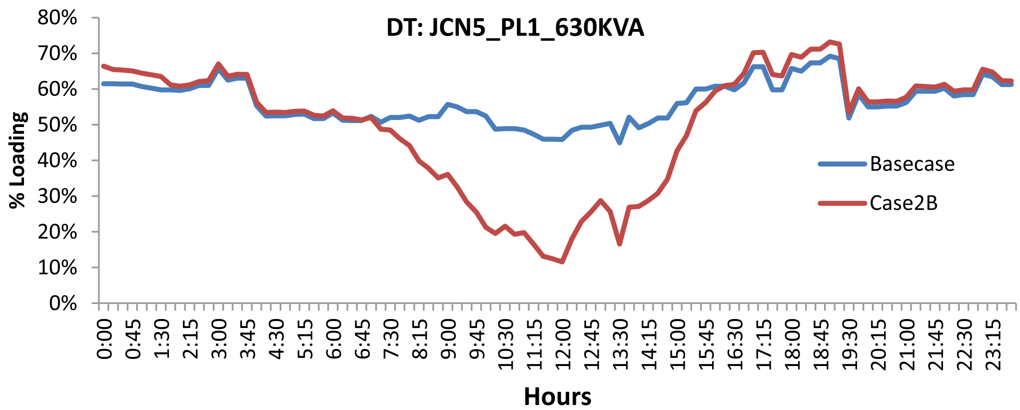


Figure 12.3.4: Transformer % loading of JCN5_PL1_630KVA

12.3.2 Janta Colony: Simulation Studies for the Year 2023

12.3.2.1 Case 1: EV Penetration

Total EVs and total charges considered in 2023 are presented in Figure 12.3.5 (a). Percentage distribution of charges with vehicle category is furnished in Figure 12.3.5 (b).

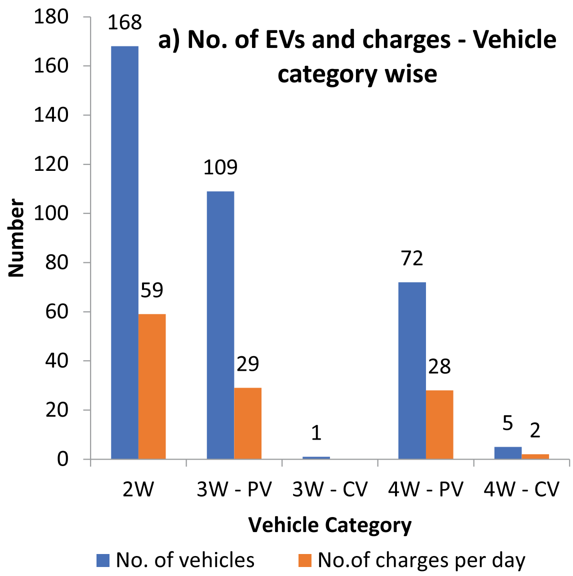


Figure 12.3.5: **a) No. of EVs and charges - Vehicle category wise b) % distribution of EVs**

Total number of EV charges per day considered in Janta colony feeder for 2023 is furnished in Table 12.3.1

Table 12.3.1: Total EV charges per day considered in Janta colony feeder for 2023

Vehicle category	Home charging	Office/Work charging	Mall/ Parking charging
2W	39	19	1
3W - PV	25	-	4
3W - CV	-	-	-
4W - PV	19	9	-
4W - CV	2	-	-
Bus	-	-	-

Total number of EV charges considered per day for different vehicle categories are distributed throughout the day in different time slots, from TS1 to TS24. EVs are plugged in at different poles under different DTs randomly. The random distribution has been selected as EV penetration under each DT will not follow uniform distribution in the future times. Random distribution of EVs for each DT in Janta colony feeder throughout the day for different time slots is presented in Table **12.3.2.**

Table 12.3.2: Random distribution of EVs under each DT in Janta colony for 2023

Name of the DT	Random distribution of EV's under each DT	Cumulative battery capacity (kWh)
JCN1_PM_630KVA	9	36
JCN2_400KVA	11	76
JCN3_PM_630KVA	19	126
JCN4_PL1_630KVA	15	85
JCN4_PL2_630KVA	12	105
JCN5_PL1_630KVA	8	50

JCN5_PL2_400KVA	13	52
JCN6_PL_630KVA	10	59
JCN7_PL1_630KVA	15	110
JCN7_PL2_630KVA	5	31
Total		**728**

Case study is executed for a period of 24 hours with the selected load profile including the EV loads plugged in at different point of times in a day. Janta colony 11 kV feeder load profile with EV loads is presented in Figure 12.3.6.

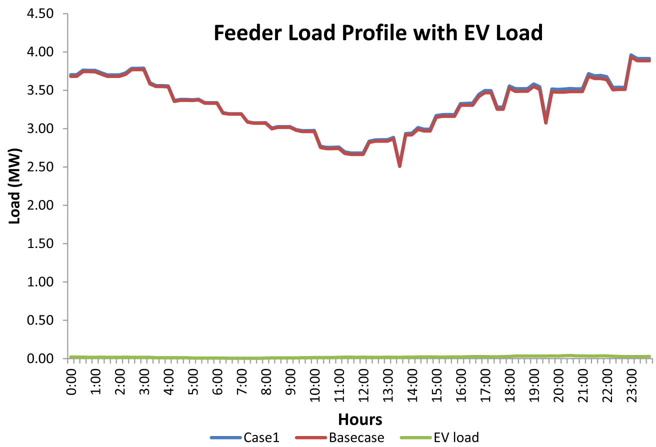


Figure 12.3.6: Janta colony feeder load profile with EV loads

From Figure 12.3.6, Peak load of the feeder is 3.96 MW at 23:00 hours and corresponding EV load of 27.75 kW is observed. EV peak load of 40.21 kW is observed at 20:30 hours and corresponding feeder loading is 3.38MW (1.19% of feeder load).

Total energy consumed by feeder is 79.65 MWh with the contribution of 0.48 MWh by the connected EV loads, which corresponds to 0.6% of feeder daily energy consumption. Energy loss is 2.69%, 2.14 MWh with EV load and summary of the observations are presented in Table 12.3.3.

Table 12.3.3: Janta colony observations for Case 1, Year 2023

Feeder peak	
Feeder peak load (MW)	3.96
Time	23:00
EV load (kW)	27.75
Maximum EV load	
EV peak (kW)	40.21
Time	20:30
Feeder load (MW)	3.380
EV peak % of feeder load	1.19%
Energy consumption	
Energy consumption by feeder (MWh)	79.65
Energy consumption by EV (MWh)	0.48
% Energy consumption by EV	0.60%

Energy supplied		
By Grid (MWh)	79.65	
By Solar PV (MWh)	-	
11kV feeder loss		
Unit	(MWh)	(%)
Case 1 (MWh)	2.141	2.69%

11kV feeder loading (in amperes) with EV load of the system is presented in Figure 12.3.7. Individual DT level loading is not presented as the loading due to EV addition is very minimal for the year 2023.

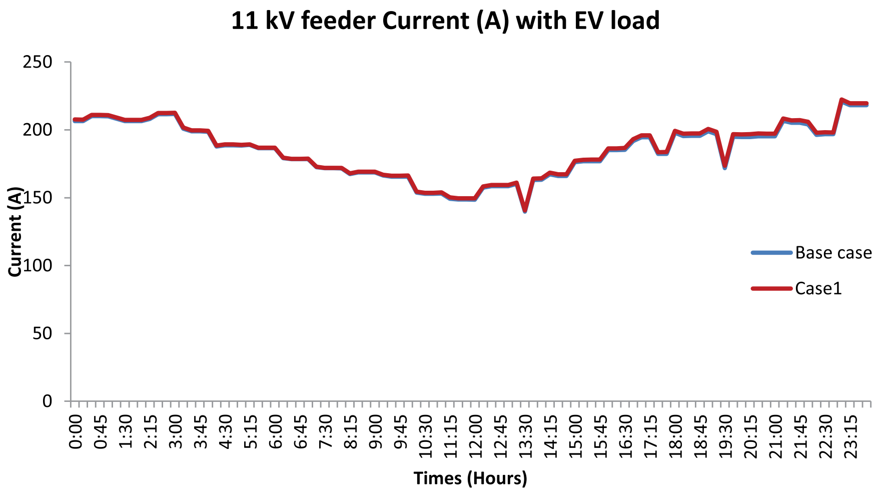


Figure 12.3.7:11 kV feeder current profile with EV loads

12.3.2.2 Case 2: EV Penetration and Solar Rooftop Penetration

Distribution network with EV penetration and typical solar generation is considered and is simulated for a period of 24 hours. Janta colony 11 kV feeder load profile with EV loads and solar rooftop generation is presented in Figure 12.3.8.

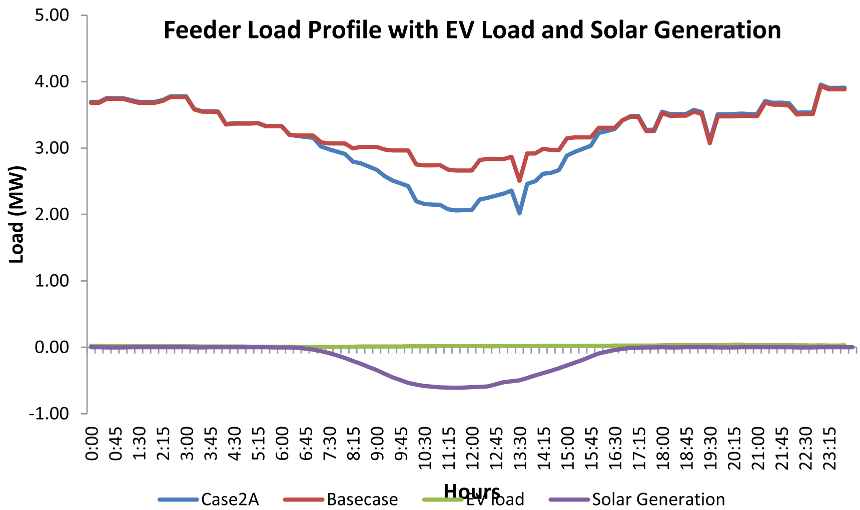


Figure 12.3.8: Janta colony feeder load profile with EV loads and solar penetration

Peak load of the feeder is 3.95 MW at 23:00 hours and corresponding EV load of 27.75 kW is observed. EV peak load of 40.21 kW is observed at 20:30 hours and corresponding feeder loading is 3.38MW (1.19% of feeder load).

Total energy consumed by feeder is 79.47 MWh with the contribution of 0.48 MWh by the connected EV loads, which corresponds to 0.6% of feeder daily energy consumption. Energy loss is 2.46%, 1.96 MWh with EV load and summary of the observations are presented in Table 12.3.4

Table 12.3.4: Janta colony 2023 observations for Case 2

Feeder peak		
Feeder peak load (MW)	3.95	
Time	23:00	
EV load (kW)	27.75	
Maximum EV load		
EV peak (kW)	40.21	
Time	20:30	
Feeder load (MW)	3.380	
EV peak % of feeder load	1.19%	
Energy consumption		
Energy consumption by feeder (MWh)	79.47	
Energy consumption by EV (MWh)	0.48	
% Energy consumption by EV	0.60%	
Energy Supplied		
By Grid (MWh)	75.83	
By Solar PV (MWh)	3.63	
11kV feeder loss		
Unit	(MWh)	(%)
Case 2 (MWh)	1.956	2.46%

11kV feeder loading (A) with EV load in the system is presented in Figure 12.3.9.

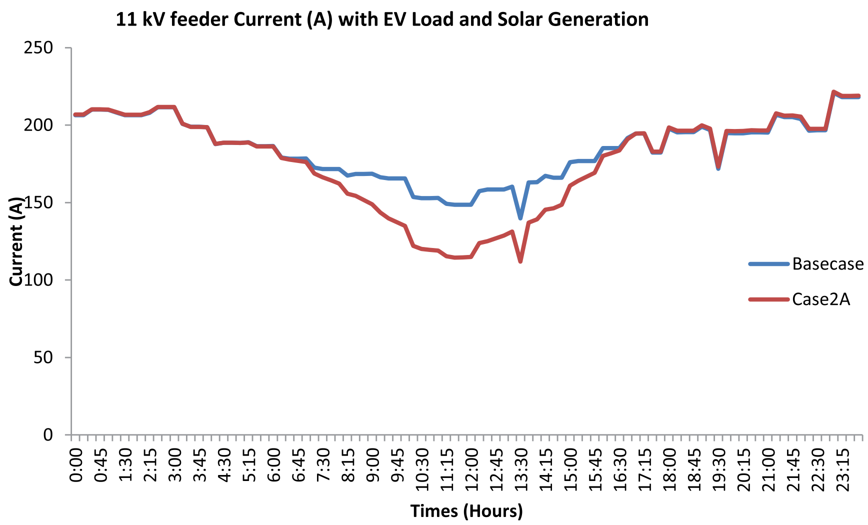


Figure 12.3.9: 11 kV feeder current profile with EV loads and typical solar generation profile

12.3.3 Janta Colony: Simulation Studies for the Year 2019

Total EVs and total charges considered in 2023 are presented in Figure 12.3.10 (a). Percentage distribution of charges with vehicle category is furnished in Figure 12.3.10 (b).

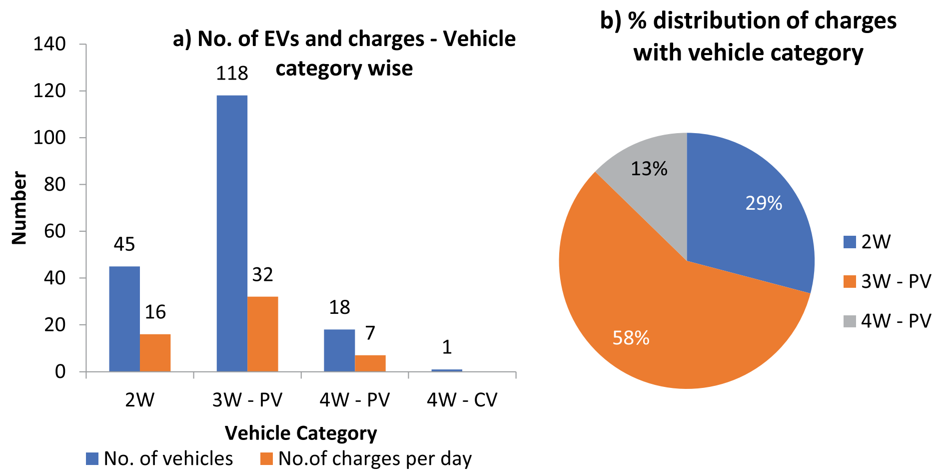


Figure 12.3.10: a) No. of EVs and charges - Vehicle category wise b) % distribution of charges with vehicle category

Total number of EV charges per day considered in Janta colony feeder for 2019 is furnished in Table 12.3.1.

Table 12.3.5: Total EV charges per day considered in Janta colony feeder for 2019

Vehicle category	Home charging	Office/Work charging	Mall/ Parking charging
2W	11	5	-
3W - PV	28	-	4
3W - CV	-	-	-
4W - PV	5	2	-
4W - CV	-	-	-
Bus	-	-	-

Total number of EV charges considered per day for different vehicle categories are distributed throughout the day in different time slots, from TS1 to TS24. EVs are plugged in at different poles under different DTs randomly. The random distribution has been selected as EV penetration under each DT will not follow uniform distribution in the future times. Random distribution of EVs for each DT in Janta colony feeder throughout the day for different time slots is presented in Table 12.3.2.

Table 12.3.6: Random distribution of EVs under each DT in Janta colony for 2019

Name of the DT	Random distribution of EV's under each DT	Cumulative battery capacity (kWh)
JCN1_PM_630KVA	6	39
JCN2_400KVA	5	30
JCN3_PM_630KVA	5	30
JCN4_PL1_630KVA	10	83

JCN4_PL2_630KVA	3	16
JCN5_PL1_630KVA	4	25
JCN5_PL2_400KVA	7	54
JCN6_PL_630KVA	10	67
JCN7_PL1_630KVA	2	14
JCN7_PL2_630KVA	3	5
Total		**361**

Case study is executed for a period of 24 hours with the selected load profile including the EV loads plugged in at different point of times in a day. Janta colony 11 kV feeder load profile with EV loads is presented in Figure 12.3.11.

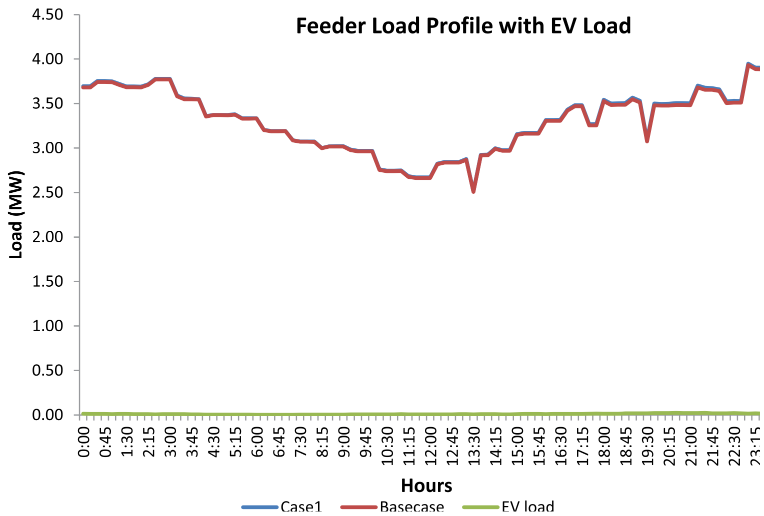


Figure 12.3.11: Janta colony feeder load profile with EV loads

From Figure 12.3.11, Peak load of the feeder is 3.95 MW at 23:00 hours and corresponding EV load of 16.69 kW is observed. EV peak load of 22.36 kW is observed at 20:30 hours and corresponding feeder loading is 3.38MW (0.66% of feeder load).

Total energy consumed by feeder is 79.41 MWh with the contribution of 0.24 MWh by the connected EV loads, which corresponds to 0.3% of feeder daily energy consumption. Energy loss is 2.69%, 2.13 MWh with EV load and summary of the observations are presented in Table 12.3.7.

Table 12.3.7: Janta colony 2019 observations for Case 1

Feeder peak	
Feeder peak load (MW)	3.95
Time	23:00
EV load (kW)	16.69
Maximum EV load	
EV peak (kW)	22.36
Time	20:30
Feeder load (MW)	3.380
EV peak % of feeder load	0.66%

Energy consumption		
Energy consumption by feeder (MWh)	79.41	
Energy consumption by EV (MWh)	0.24	
% Energy consumption by EV	0.30%	
Energy Supplied		
By Grid (MWh)	79.41	
By Solar PV (MWh)	-	
11kV feeder loss		
Unit	(MWh)	(%)
Case 1 (MWh)	2.133	2.69%

11kV feeder loading (A) with EV load in the system is presented in Figure 12.3.12.

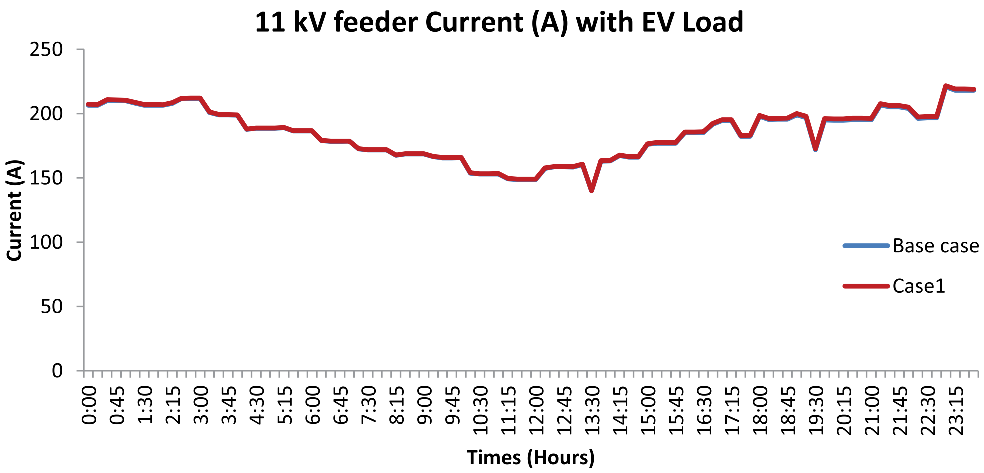


Figure 12.3.12: 11 kV feeder current profile with EV loads

12.4 Arya Samaj: Simulations for 2023 and 2019

12.4.1 Arya Samaj: Simulation studies for the year 2023

Lower EV battery sizes are considered for the year 2023. Taking average daily distance commuted by all the vehicle categories as reference, total number of charges per vehicle per year with 25% initial SOC is calculated. Battery capacities considered as per current trends in India and their corresponding number of charges per year is presented in Table 12.4.1.

Table 12.4.1: EV Battery capacities considered for year 2023

Vehicle Category	Battery Capacity (kWh)	No. of charges per year per vehicle
2W	1.5	130
3W - PV	4	608
3W - CV	7	389
4W - PV	15	145
4W - CV	15	886
Bus	120	811

Cases considered for Arya samaj feeder for year 2023 is presented in Figure 8.1.4.

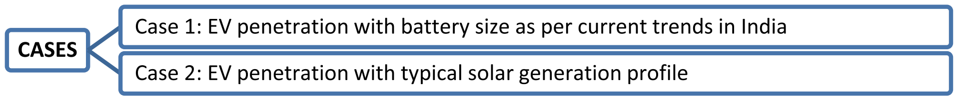


Figure 12.4.1: Cases considered for Arya samaj feeder for year 2023

Table 12.4.2: Description for cases considered for Arya samaj feeder for year 2023

Case description	EV	Solar profile A
Case-1	ü	×
Case-2	✓	✓

12.4.1.1 Case 1: EV Penetration

Total EVs and total charges considered in 2023 are presented in Figure 12.4.2 (a). Percentage distribution of charges with vehicle category is furnished in Figure 12.4.2 (b)

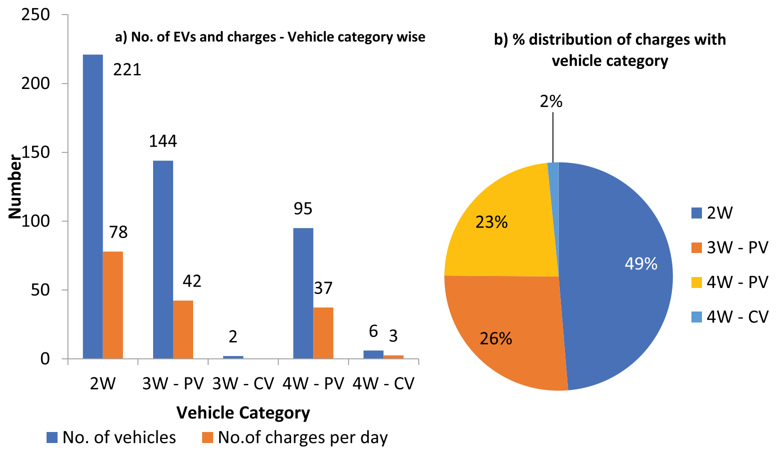


Figure 12.4.2: a) No. of EVs and charges - Vehicle category wise b) % distribution of EVs

Total number of EV charges per day considered in Arya samaj feeder for 2023 is furnished in Table 12.4.3

Table 12.4.3: Total EV charges per day considered in Arya samaj feeder for 2023

Vehicle category	Home charging	Office/Work charging	Mall/ Parking charging
2W	51	25	1
3W - PV	34	-	5
3W - CV	-	-	-
4W - PV	24	12	1
4W - CV	2	-	-
Bus	-	-	-

Total number of EV charges considered per day for different vehicle categories are distributed throughout the day in different time slots, from TS1 to TS24. EVs are plugged in at different poles under different DTs randomly. The random distribution has been selected as EV penetration under each DT will not follow uniform distribution in the future times. Random distribution of

EVs for each DT in Arya samaj feeder throughout the day for different time slots is presented in Table 12.4.4

Table 12.4.4: Random distribution of EVs for each DT in Arya samaj for 2023

Random distribution of EVs under each DT		
Name of the DT	No. of EVs plugged in a day	Cumulative battery capacity (kWh)
TRF-1:ARYA SAMAJ ROAD NALA	32	187
TRF-2:ARYA SAMAJ ROAD NALA	31	215
TRF-1:R.K.DASS-1 K.BAGH	22	148
TRF-2:R.K.DASS-1 K.BAGH	24	135
TRF-1:R.K.DASS-1/2 K.BAGH	24	146
TRF-2:R.K.DASS-1/2 K. BAGH	23	153
Total		**983**

Case study is executed for a period of 24 hours with the selected load profile including the EV loads plugged in at different point of times in a day.

Arya samaj 11 kV feeder load profile with EV loads is presented in Figure 12.4.3

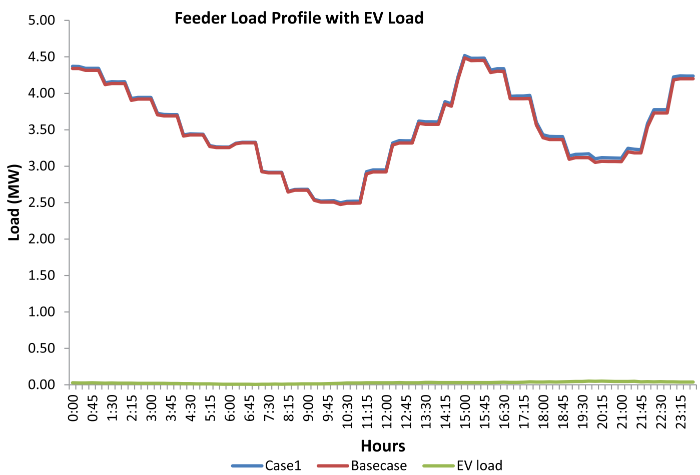


Figure 12.4.3: Arya Samaj feeder load profile with EV loads

Peak load of the feeder is 4.52 MW at 15:00 hours and corresponding EV load of 29.67 kW is observed. EV peak load of 50.76 kW is observed at 19:45 hours and corresponding feeder loading is 3.04MW (1.67% of feeder load).

Total energy consumed by feeder is 84.26 MWh with the contribution of 0.65 MWh by the connected EV loads, which corresponds to 0.77% of feeder daily energy consumption. Energy loss is 2.95%, 2.49 MWh with EV load and summary of the observations are presented in Table 12.3.3.

Table 12.4.5: Arya Samaj observations for Case 1, Year 2023

Feeder peak		
Feeder peak load (MW)	4.52	
Time	15:00	
EV load (kW)	29.67	
Maximum EV load		
EV peak (kW)	50.76	
Time	19:45	
Feeder load (MW)	3.036	
EV peak % of feeder load	1.67%	
Energy consumption		
Energy consumption by feeder (MWh)	84.26	
Energy consumption by EV (MWh)	0.65	
% Energy consumption by EV	0.77%	
Energy supplied		
By Grid (MWh)	84.26	
By Solar PV (MWh)	-	
11kV feeder loss		
Unit	(MWh)	(%)
Case 1 (MWh)	2.49	2.95%

11kV feeder loading (in ampere) with EV load of the system is presented in Figure 12.3.7. Individual DT level loading is not presented as the loading due to EV addition is very minimal for the year 2023.

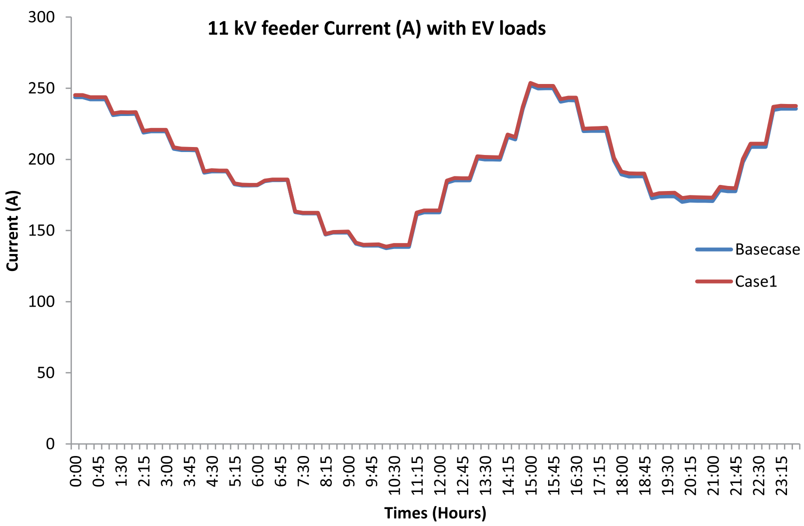


Figure 12.4.4:11 kV feeder current profile with EV loads

12.4.1.2 Case 2: EV Penetration and Solar Rooftop Penetration

Distribution network with EV penetration and typical solar generation is considered and is simulated for a period of 24 hours. Arya Samaj 11 kV feeder load profile with EV loads and solar rooftop generation is presented in Figure 12.3.8.

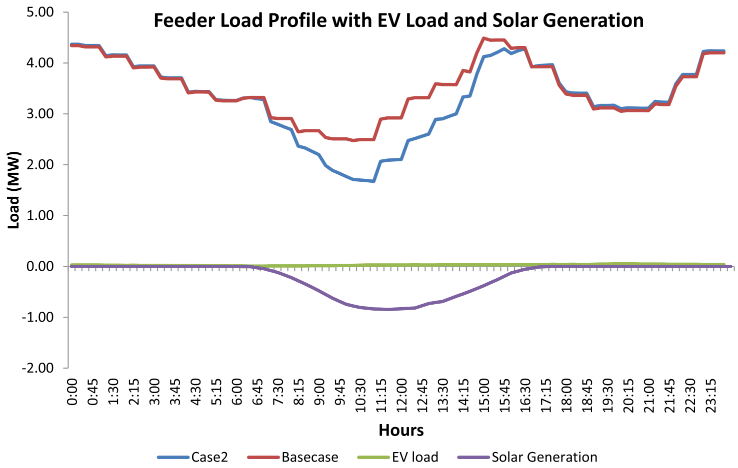


Figure 12.4.5: **Arya Samaj feeder load profile with EV loads and solar penetration**

Peak load of the feeder is 4.37 MW at 00:00 hours and corresponding EV load of 27.51 kW is observed. EV peak load of 50.76 kW is observed at 19:45 hours and corresponding feeder loading is 3.04MW (1.67% of feeder load).

Total energy consumed by feeder is 84.14 MWh with the contribution of 0.65 MWh by the connected EV loads, which corresponds to 0.78% of feeder daily energy consumption. Energy loss is 2.81%, 2.37 MWh with EV load and summary of the observations are presented in Table 12.3.4

Table 12.4.6: Arya Samaj 2023 observations for Case 2

Feeder peak		
Feeder peak load (MW)	4.37	
Time	0:00	
EV load (kW)	27.51	
Maximum EV load		
EV peak (kW)	50.76	
Time	19:45	
Feeder load (MW)	3.036	
EV peak % of feeder load	1.67%	
Energy consumption		
Energy consumption by feeder (MWh)	84.14	
Energy consumption by EV (MWh)	0.65	
% Energy consumption by EV	0.78%	
Energy supplied		
By Grid (MWh)	79.10	
By Solar PV (MWh)	5.04	
11kV feeder loss		
Unit	(MWh)	(%)
Case 2 (MWh)	2.37	2.81%

11kV feeder loading (A) with EV load in the system is presented in Figure 12.3.9.

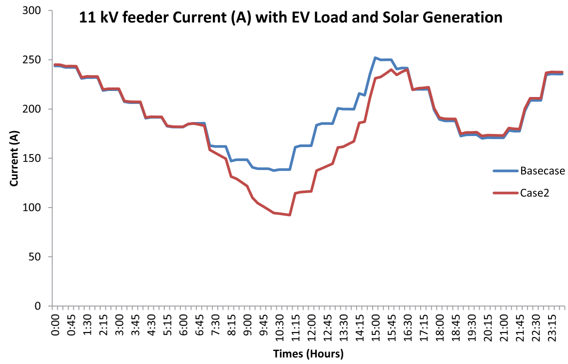


Figure 12.4.6: 11 kV feeder current profile with EV loads and typical solar generation profile

12.4.2 Arya Samaj: Simulation Studies for the Year 2019

Total EVs and total charges considered in 2019 are presented in Figure 12.4.2 (a). Percentage distribution of charges with vehicle category is furnished in Figure 12.4.2 (b).

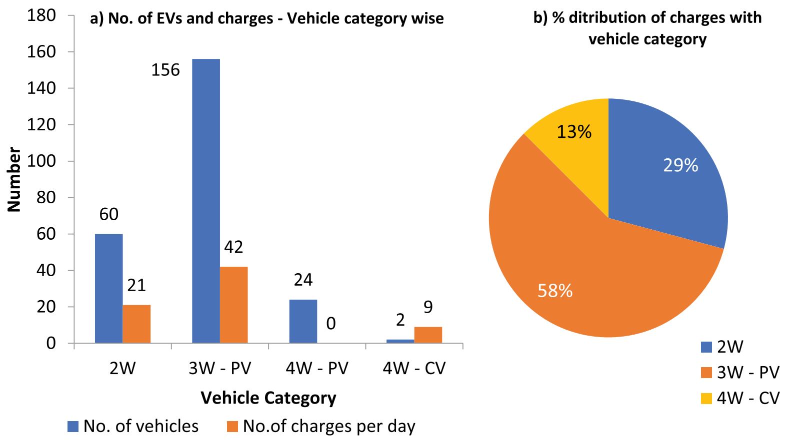


Figure 12.4.7: a) No. of EVs and charges - Vehicle category wise b) % distribution of EVs

Total number of EV charges per day considered in Arya samaj feeder for 2019 is furnished in Table 12.4.7

Table 12.4.7: Total EV charges per day considered in Arya samaj feeder for 2019

Vehicle category	Home charging	Office/Work charging	Mall/ Parking charging
2W	14	7	-
3W - PV	37	-	5
3W - CV	-	-	-
4W - PV	6	3	-
4W - CV	1	-	-
Bus	-	-	-

Total number of EV charges considered per day for different vehicle categories are distributed throughout the day in different time slots, from TS1 to TS24. EVs are plugged in at different poles under different DTs randomly. The random distribution has been selected as EV penetration under each DT will not follow uniform distribution in the future times. Random distribution of

EVs for each DT in Arya samaj feeder throughout the day for different time slots is presented in Table 12.4.8

Table 12.4.8: Random distribution of EVs for each DT in Arya samaj for 2019

Random distribution of EVs under each DT		
Name of the DT	**No. of EVs plugged in a day**	**Cumulative battery capacity (kWh)**
TRF-1:ARYA SAMAJ ROAD NALA	13	91
TRF-2:ARYA SAMAJ ROAD NALA	9	49
TRF-1:R.K.DASS-1 K.BAGH	16	120
TRF-2:R.K.DASS-1 K.BAGH	9	68
TRF-1:R.K.DASS-1/2 K.BAGH	15	94
TRF-2:R.K.DASS-1/2 K. BAGH	11	55
Total		**476**

Case study is executed for a period of 24 hours with the selected load profile including the EV loads plugged in at different point of times in a day.

11kV feeder profile with EV loads for the year 2019 is furnished in Figure 12.4.9

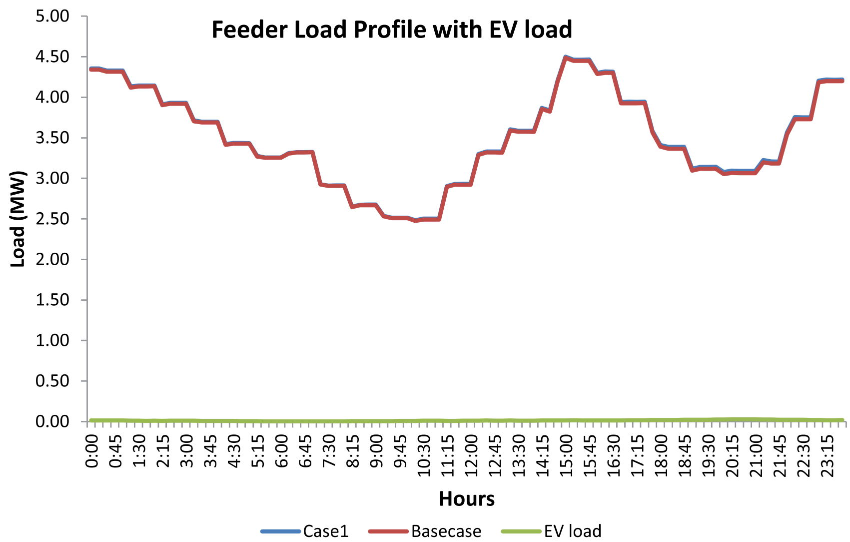


Figure 12.4.8: Arya Samaj feeder load profile with EV loads

From Figure 12.4.9, feeder peak load of the feeder is 4.5 MW at 15:00 hours and corresponding EV load of 13.97 kW is observed. EV peak load of 28.16 kW is observed at 20:30 hours and corresponding feeder loading is 2.99MW (0.94% of feeder load).

Total energy consumed by feeder is 83.9 MWh with the contribution of 0.31 MWh by the connected EV loads, which corresponds to 0.37% of feeder daily energy consumption. Energy loss is 2.94%, 2.47 MWh with EV load and summary of the observations are presented in Table 12.3.7.

Table 12.4.9: Arya Samaj 2019 observations for Case 1

Feeder peak		
Feeder peak load (MW)	4.50	
Time	15:00	
EV load (kW)	13.97	
Maximum EV load		
EV peak (kW)	28.16	
Time	20:30	
Feeder load (MW)	2.987	
EV peak % of feeder load	0.94%	
Energy consumption		
Energy consumption by feeder (MWh)	83.90	
Energy consumption by EV (MWh)	0.31	
% Energy consumption by EV	0.37%	
Energy Supplied		
By Grid (MWh)	83.90	
By Solar PV (MWh)	-	
11kV feeder loss		
Unit	(MWh)	(%)
Case 1 (MWh)	2.47	2.94%

11kV feeder loading (A) with EV load in the system is presented in Figure 12.4.9

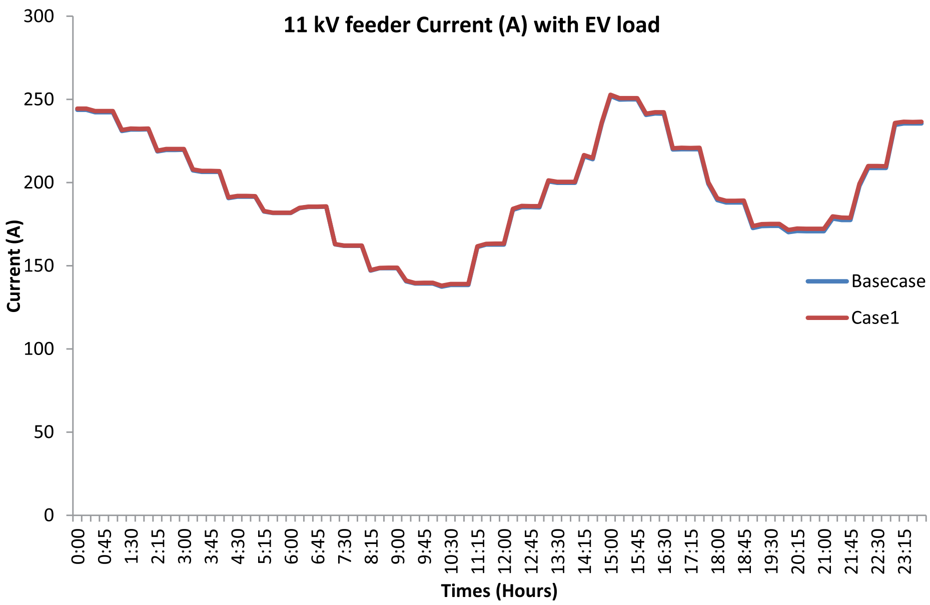


Figure 12.4.9: 11 kV feeder current profile with EV loads

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